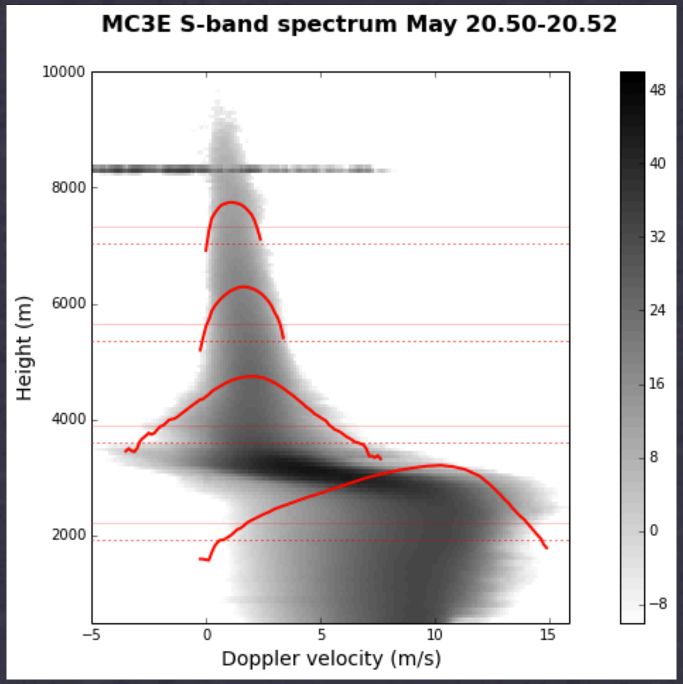
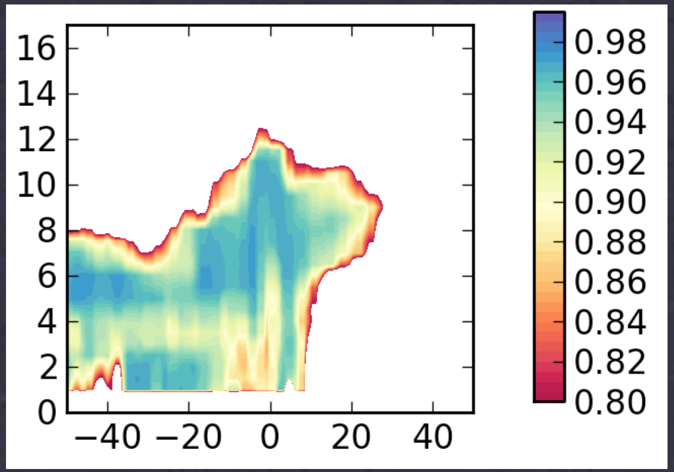
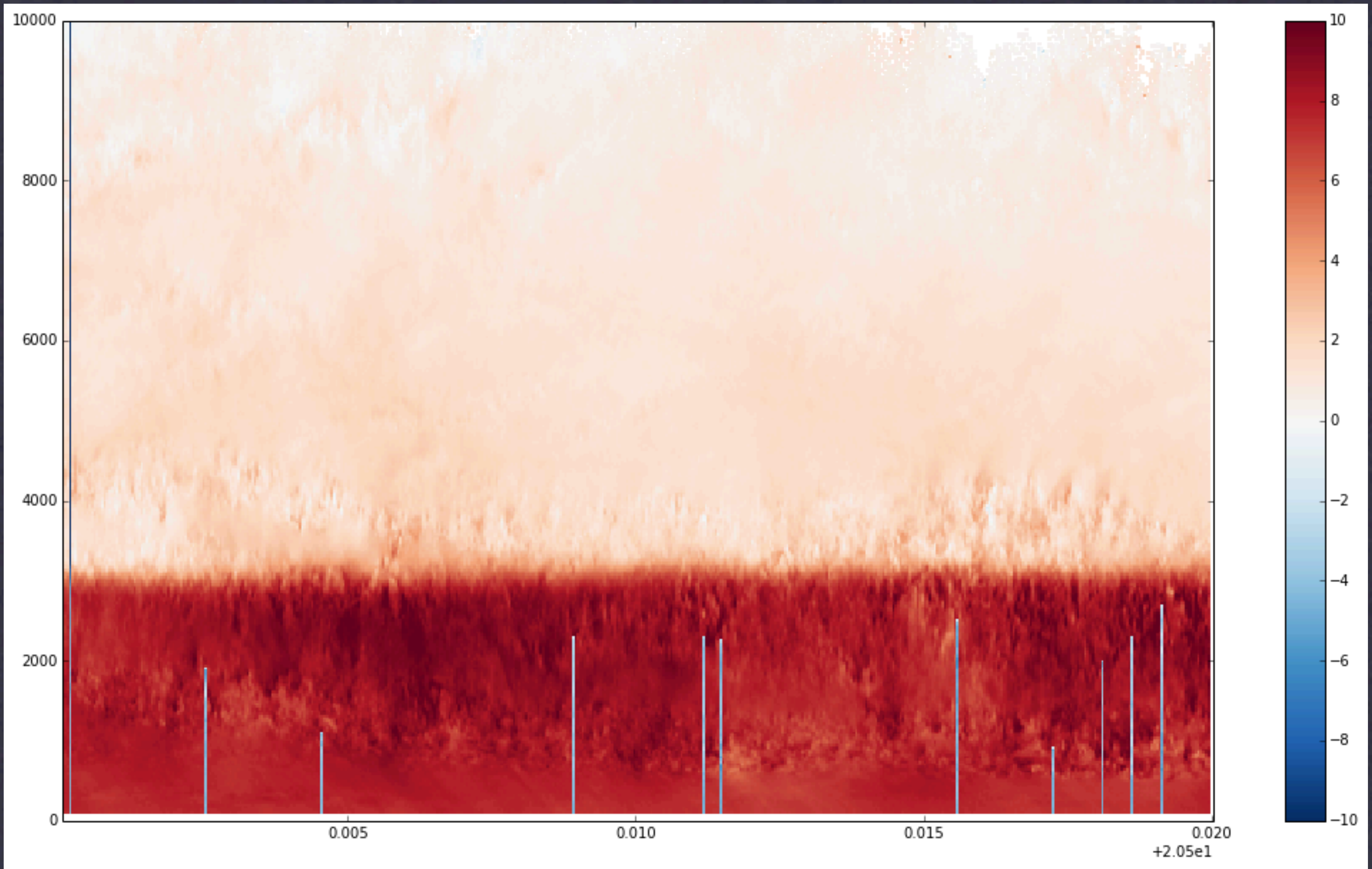






Exploring new radar constraints on cloud microphysical uncertainty

Marcus van Lier-Walqui
CCSR, Columbia Univsersity & NASA/GISS

“New” radar observations

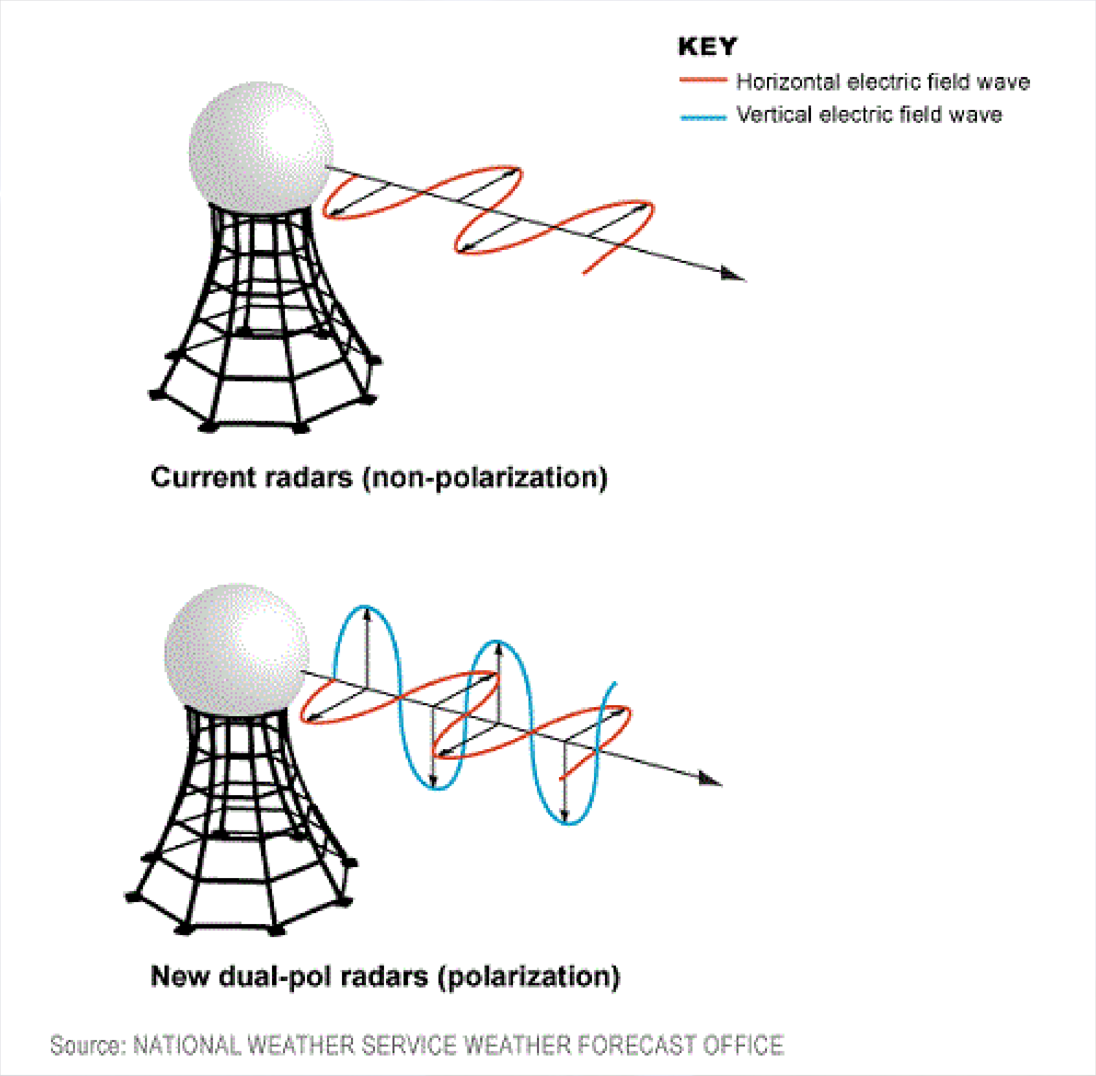
- Polarimetric Radar
  - Not “new” (e.g. Seliga & Bringi 1976)
  - Information about shape, phase, habit, particle size distribution of hydrometeors
  - Area of active research to determine information relevant to micorphysics
- Doppler Spectra
  - Also not new (fundamental derived variable from radar)
  - 0th moment: Reflectivity, 1st moment: mean Doppler velocity...
  - Vertically pointing: gives information about PSD of precip & air motion.

What questions can polarimetric radar help with?

- What are the characteristics of deep convective updrafts (in mid-latitudes and tropics)?
- Cloud resolving models tend to overestimate w (Varble et al. 2014)
- Multi-Doppler retrievals are far from perfect, can polarimetric radar fill in the gaps?
  - www.giss.nasa.gov/staff/mvanlier-walqui/wind_pol_520.html

Polarimetric radar

- Transmit both horizontally and vertically polarized waves
- Compare returned horizontal and vertical signals
- Provides information on shape/cant/phase, etc.
- NWS NEXRAD radar network completed polarimetric upgrade this year

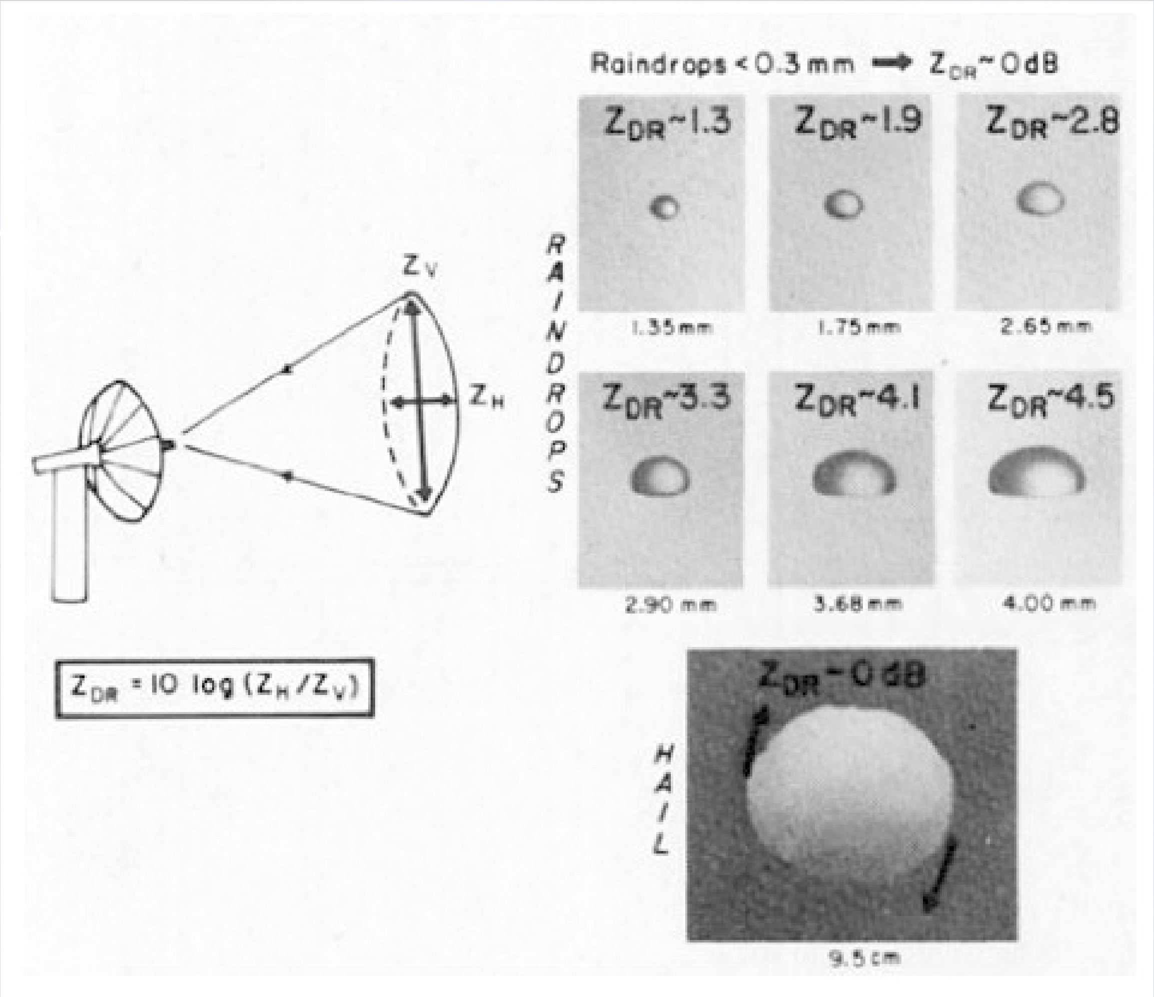


Polarimetric variables – ZDR

Differential reflectivity

$$Z_{DR} = 10\log_{10}(z_{hh}/z_{vv})$$

- Sensitive to oblateness of particles ∴ rain size
- Insensitive to concentration
- Strongly affected by attenuation



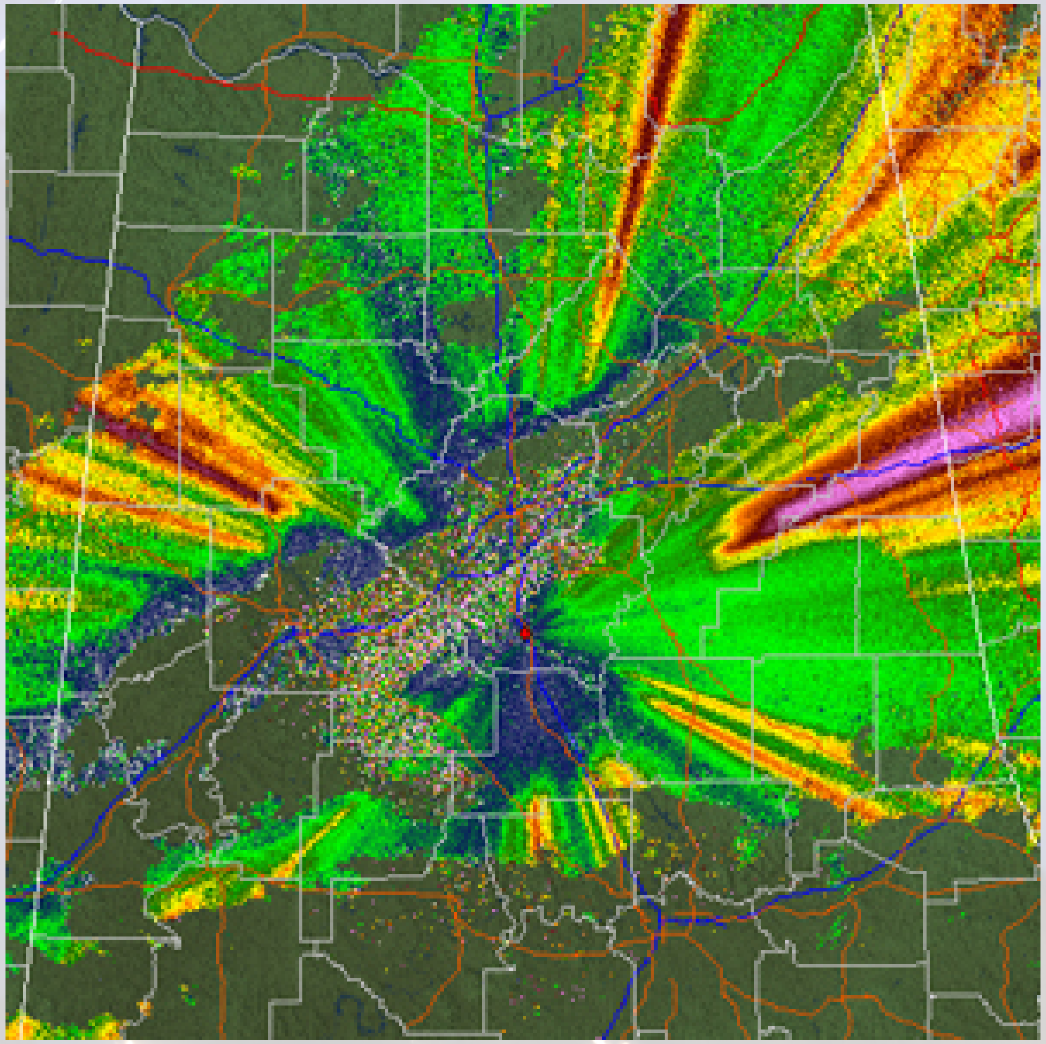
From Wakimoto & Bringi (Monthly Weather Review 1988).

Polarimetric variables – Φ_{DP} & K_{DP}

Differential Phase (Φ_{DP})& Specific Differential Phase (K_{DP})

- Difference in phase between horizontal and vertical pulses
- Similar in some ways to ZDR
- Insensitive to attenuation
- Sensitive to concentration
- K_{DP} = range derivative of Φ_{DP}

Φ_{DP}



Polarimetric variables – Φ_{DP} & K_{DP}

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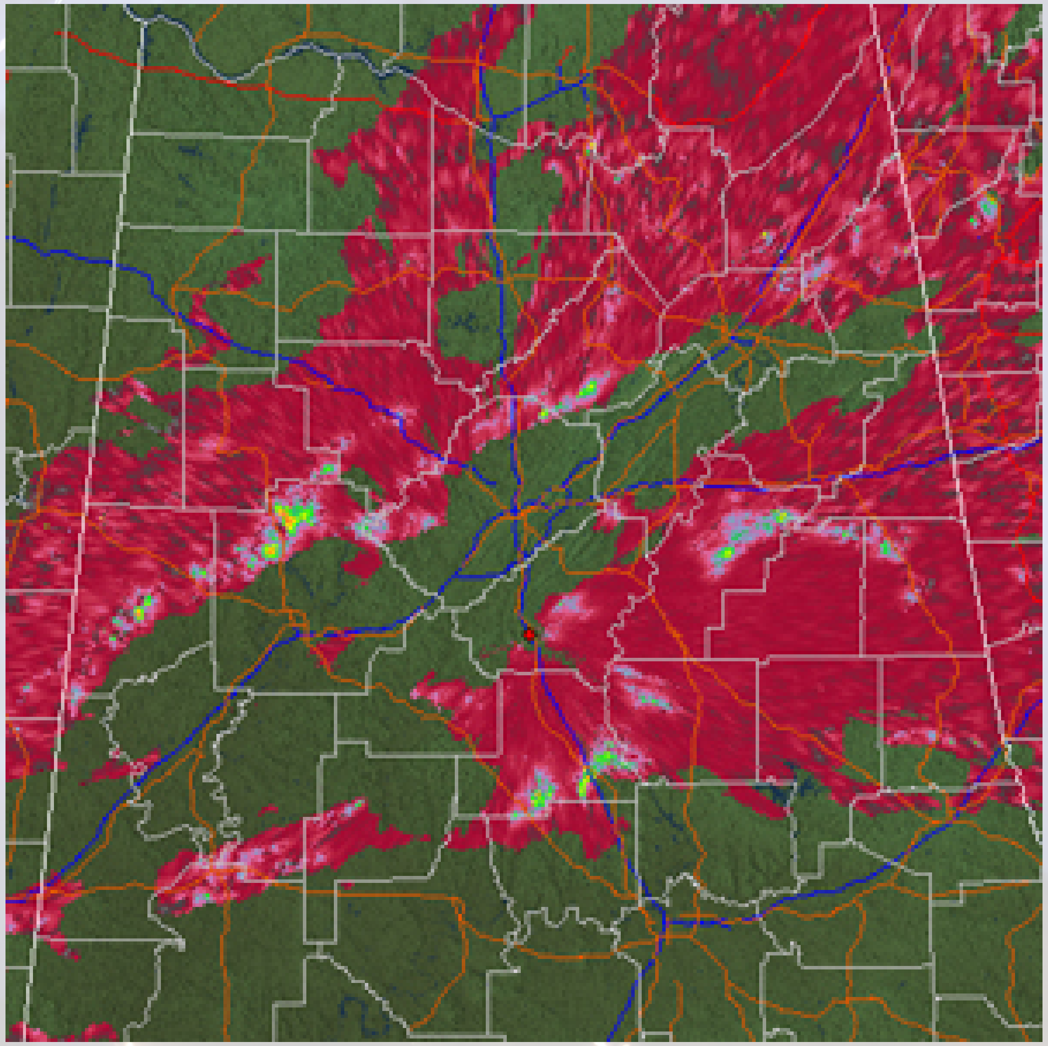
K_{DP}



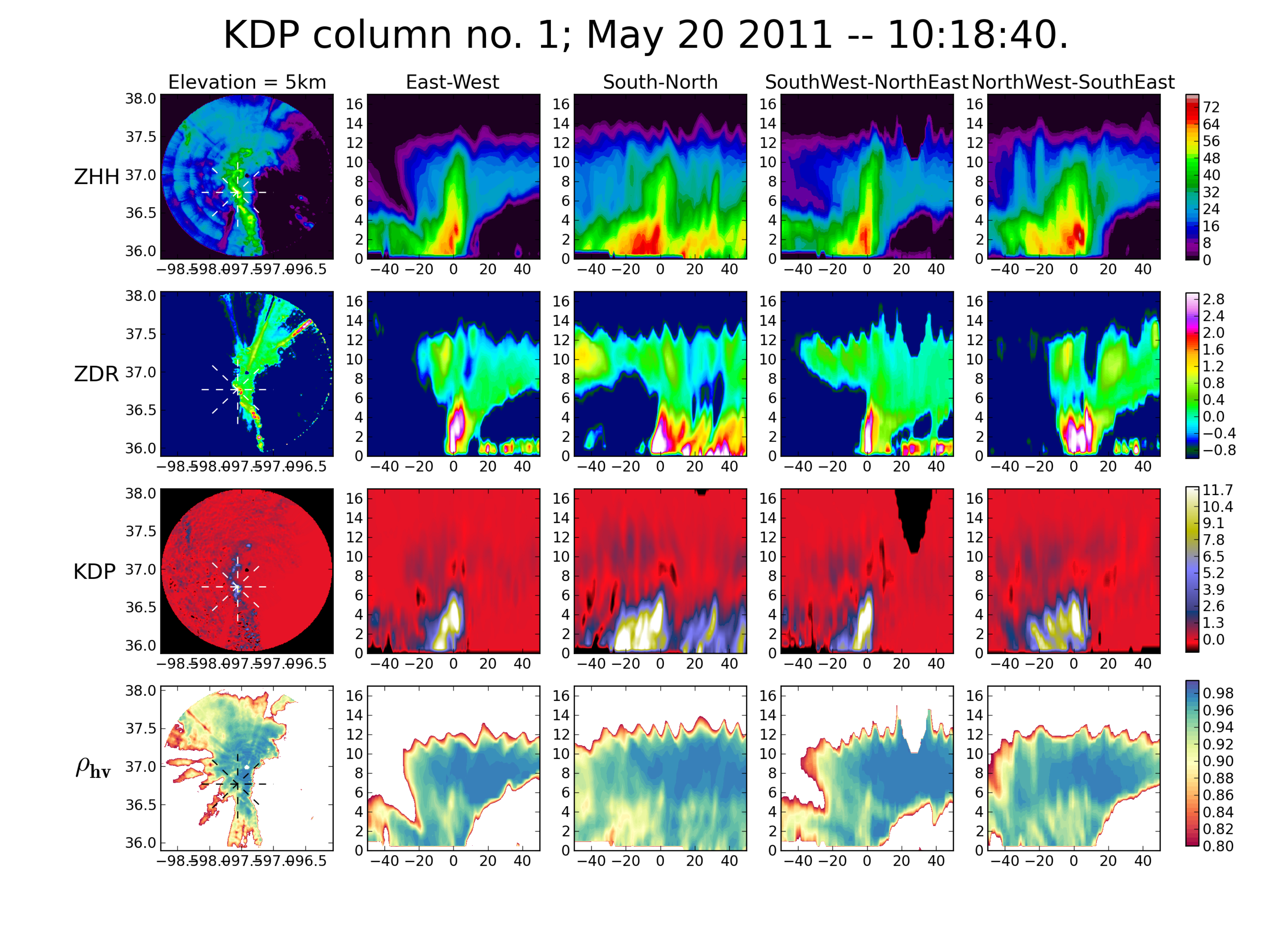
Polarimetric variables – Summary

TABLE 1. Attributes of polarimetric variables (for 5- and 10-cm wavelengths).

Attribute / Variable	Independent of absolute radar	Immune to propagation effects calibration	Immune to noise bias	Used for quantitative estimation	Independent of concen-tration
Z_h	no	no	no	yes	no
Z_{DR}	yes	no	no	yes	yes
K_{DP}	yes	yes	yes	yes	no
ρ_{hv}	yes	yes	no	no	yes
δ	yes	no	yes	no	yes
LDR	yes	no	no	no	yes

Zrnic & Ryzhkov (BAMS 1999)

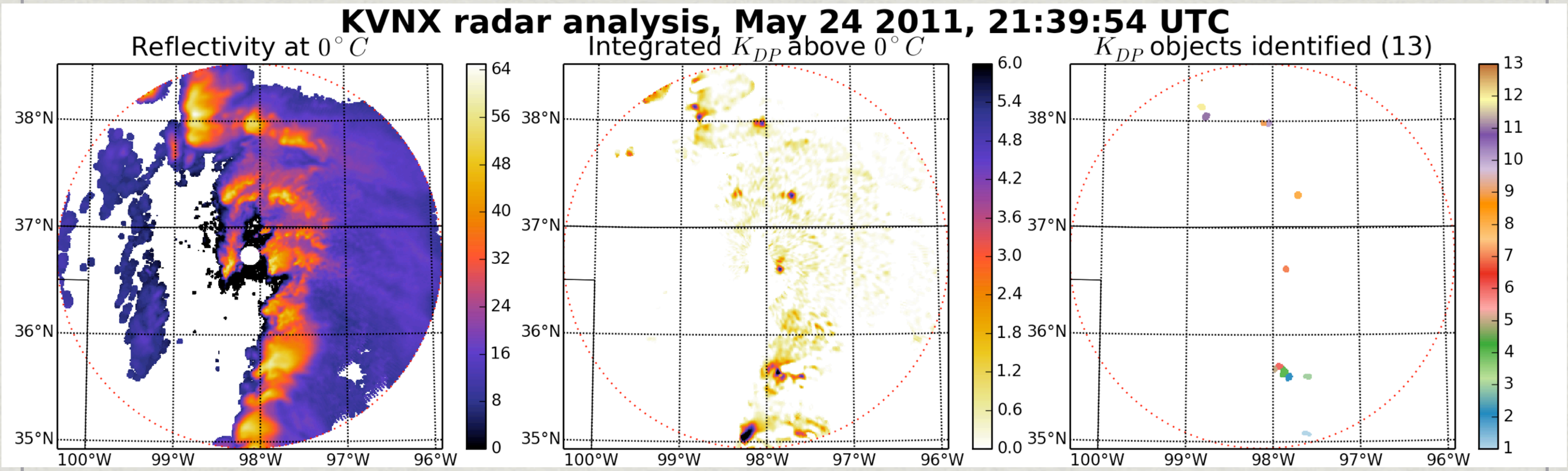
KDP & ZDR columns



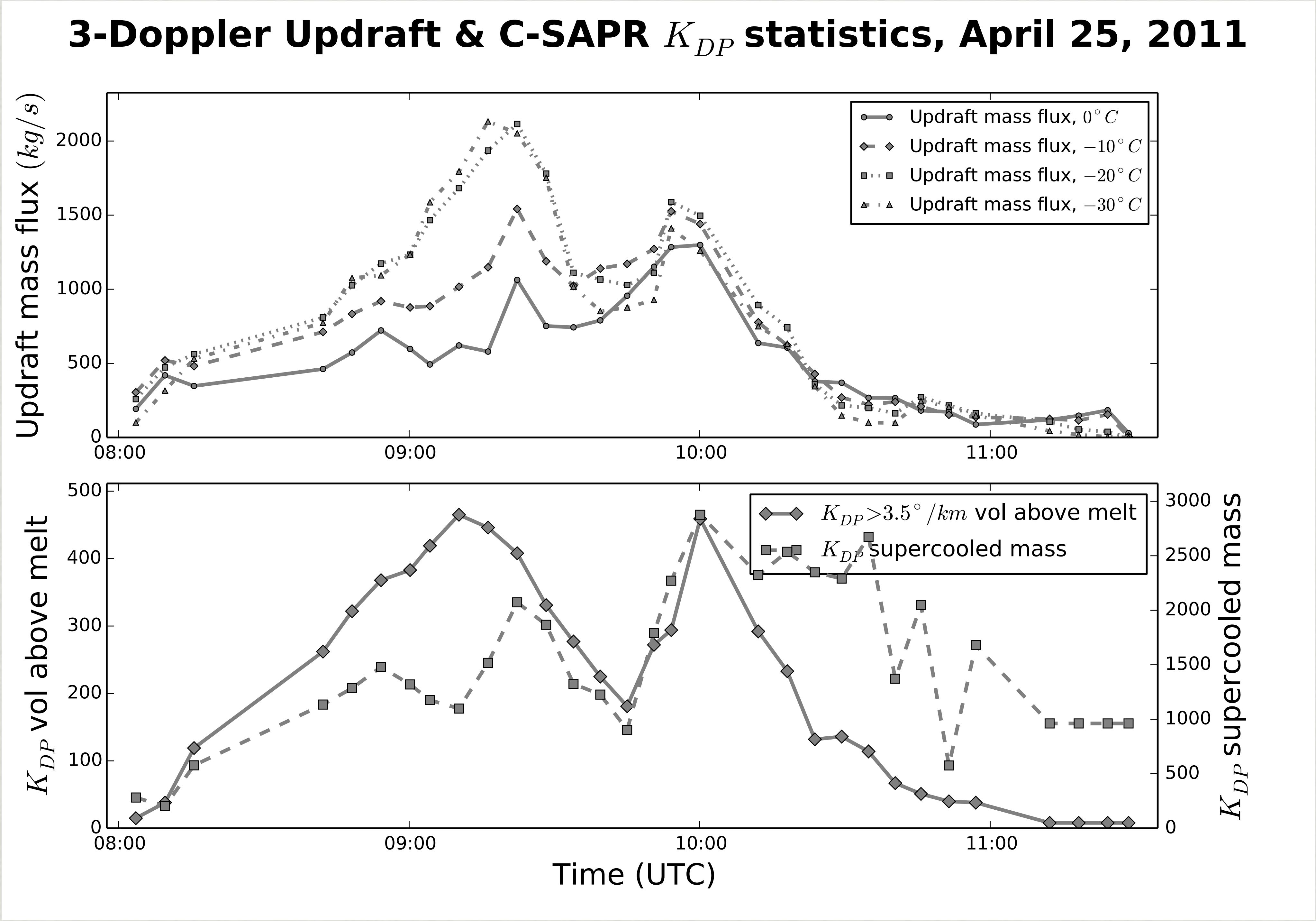
Investigation of KDP columns in deep convective updrafts

- Midlatitude Continental Convective Clouds Experiment (MC3E): OK, Late Spring 2011
- Analyze KDP observed above the environmental melting level as proxy of deep convective updraft
- Compare with multi-Doppler winds, lightning flash rate, ZDR, precipitation estimates
- Co-authors: Ann Fridlind, Andrew Ackerman, Scott Collis, Jonathan Helmus, Kirk North, Pavlos Kollias, Don MacGorman, Derek Posselt

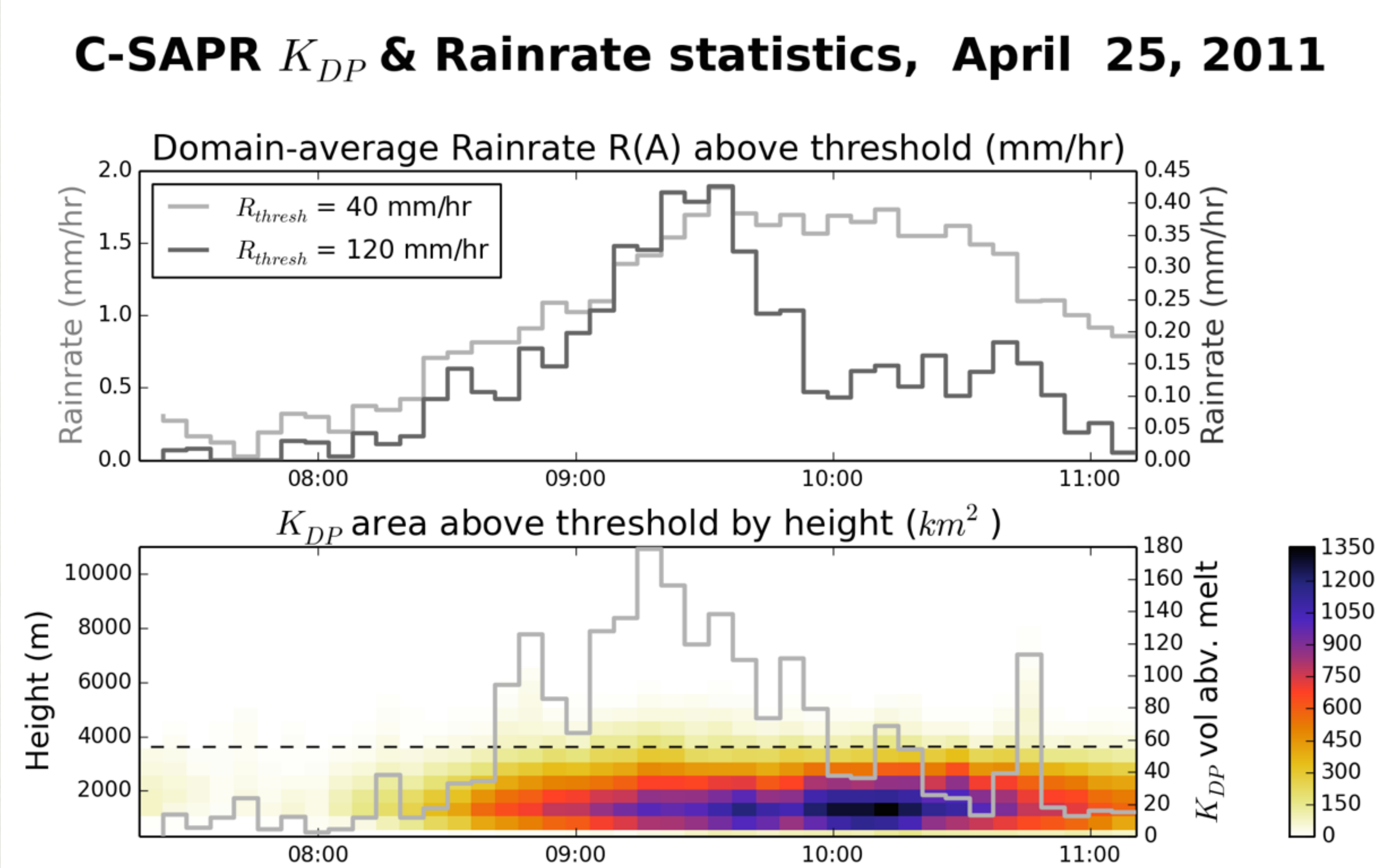
Identifying KDP columns



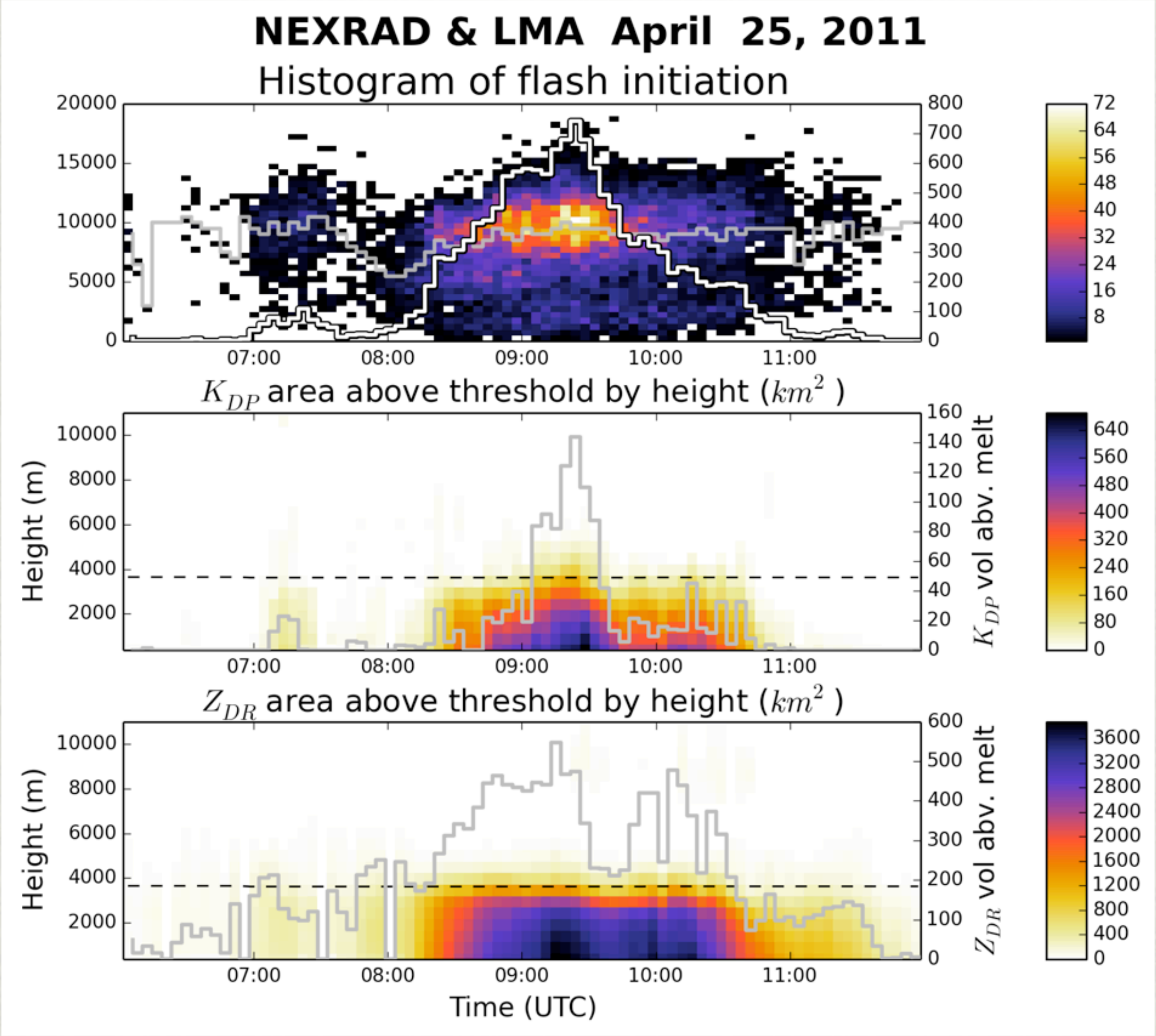
Updrafts vs. KDP column volume



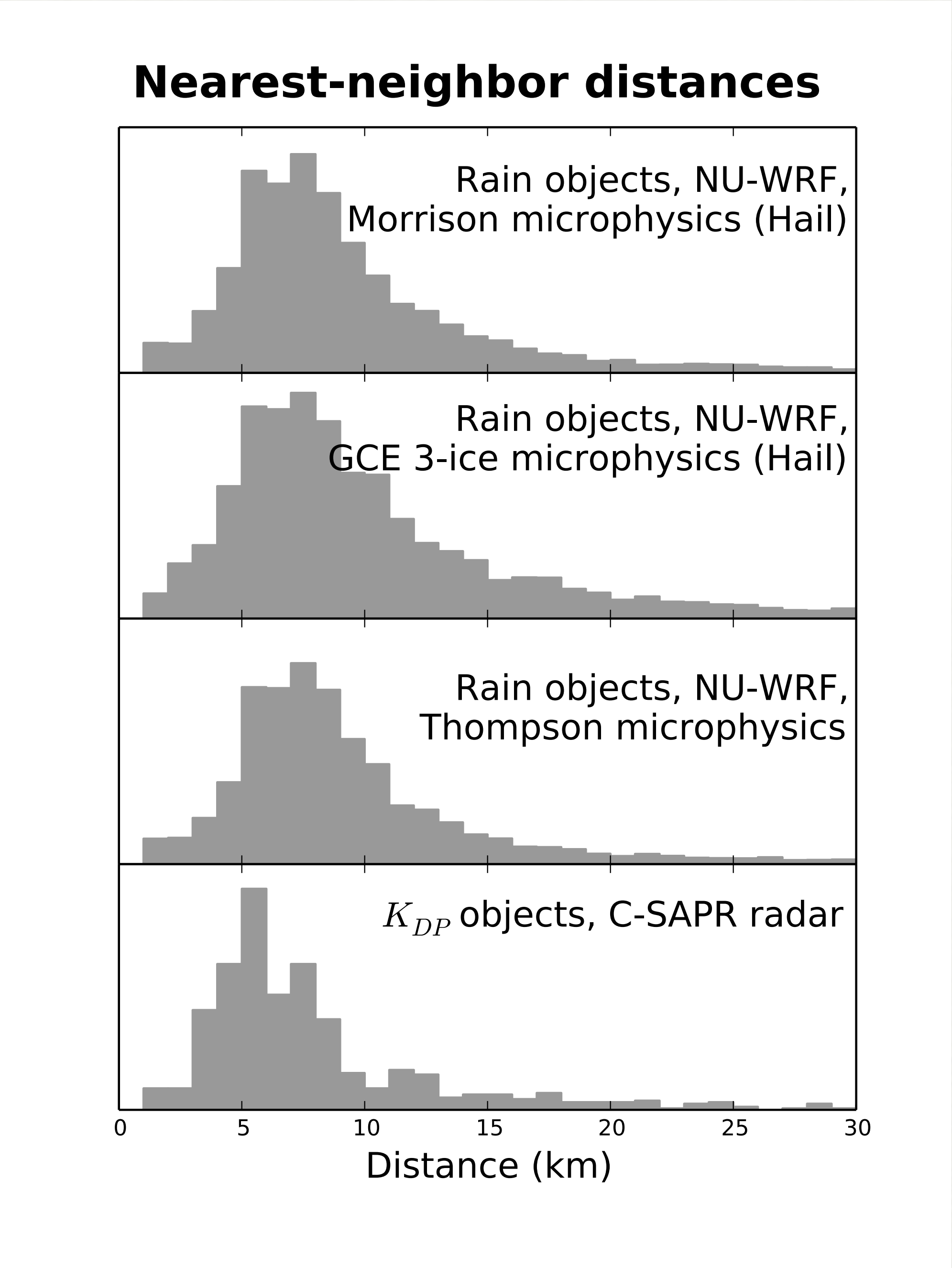
KDP columns and Intense precipitation

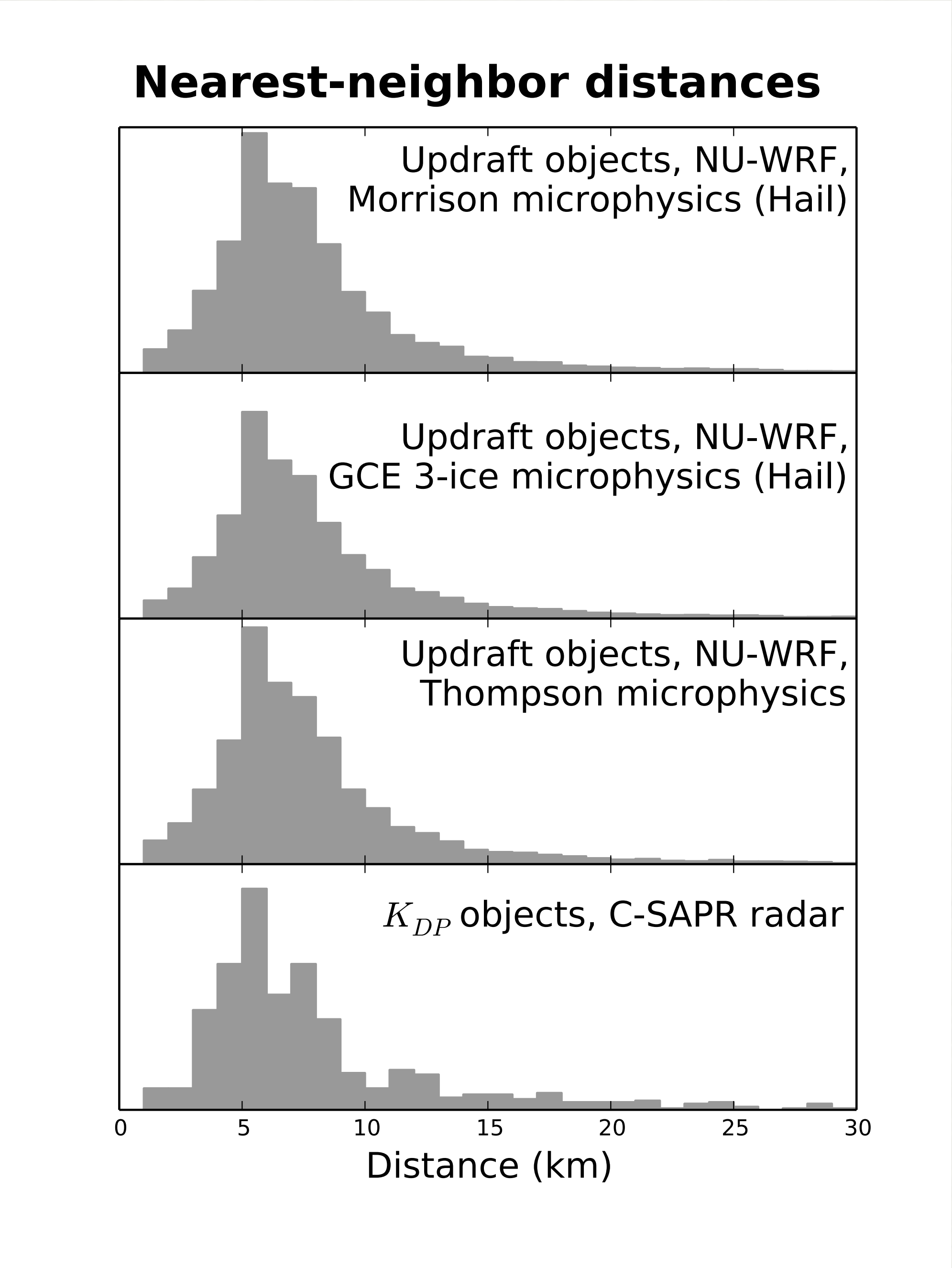


KDP columns and lightning flash rate



Also: Spatial statistics of updraft features





Summary:

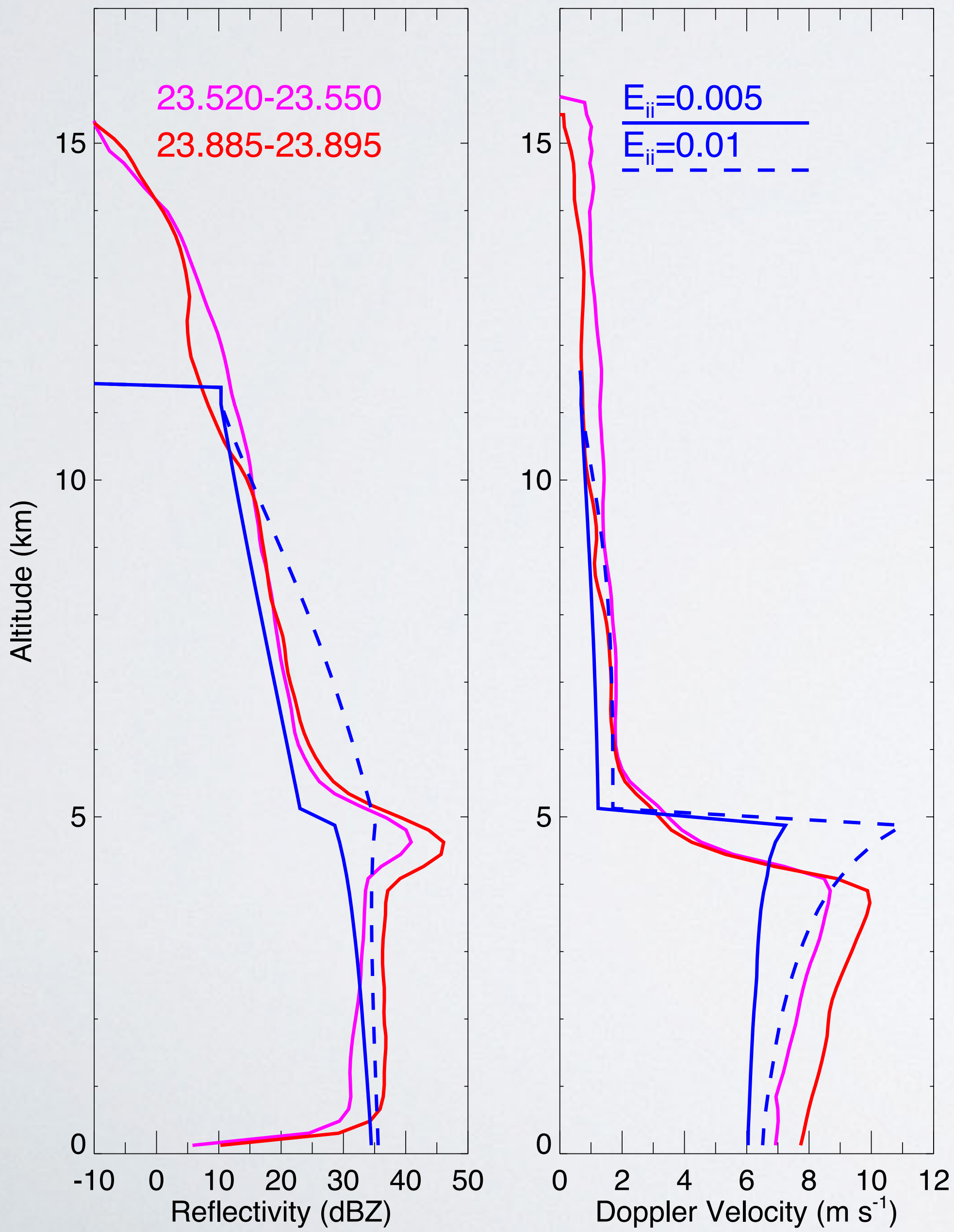
- Polarimetric radar variables such as KDP provide valuable information related to deep convective updrafts; information that is necessary to constrain model behavior
- Still to do: Detailed comparison with modeled results using bin and bulk microphysical parameterization schemes and a polarimetric foward operator

Profiling radar Doppler spectra

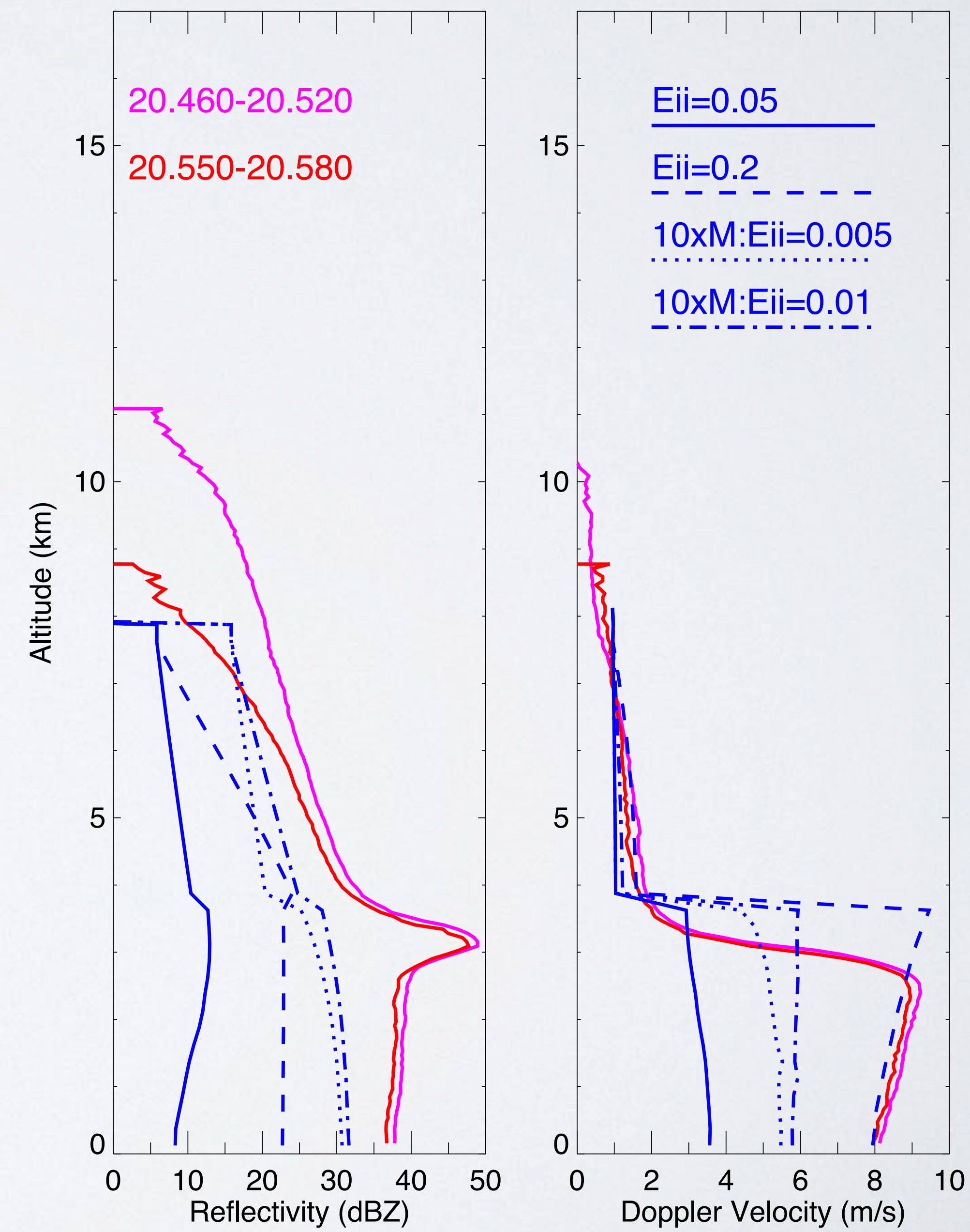
- In-situ observations are available to constrain cloud-top ice properties in stratiform precipitation associated with deep convection:
    - http://www.giss.nasa.gov/staff/mvanlier-walqui/kvnx_citation_20110520.html
    - http://www.giss.nasa.gov/staff/mvanlier-walqui/nexrad_gridplots/nex_520_lev07.html
- Microphysics of aggregation of ice largely unconstrained (ie. ice-ice sticking efficiency)

Ice sticking uncertainty

TWP



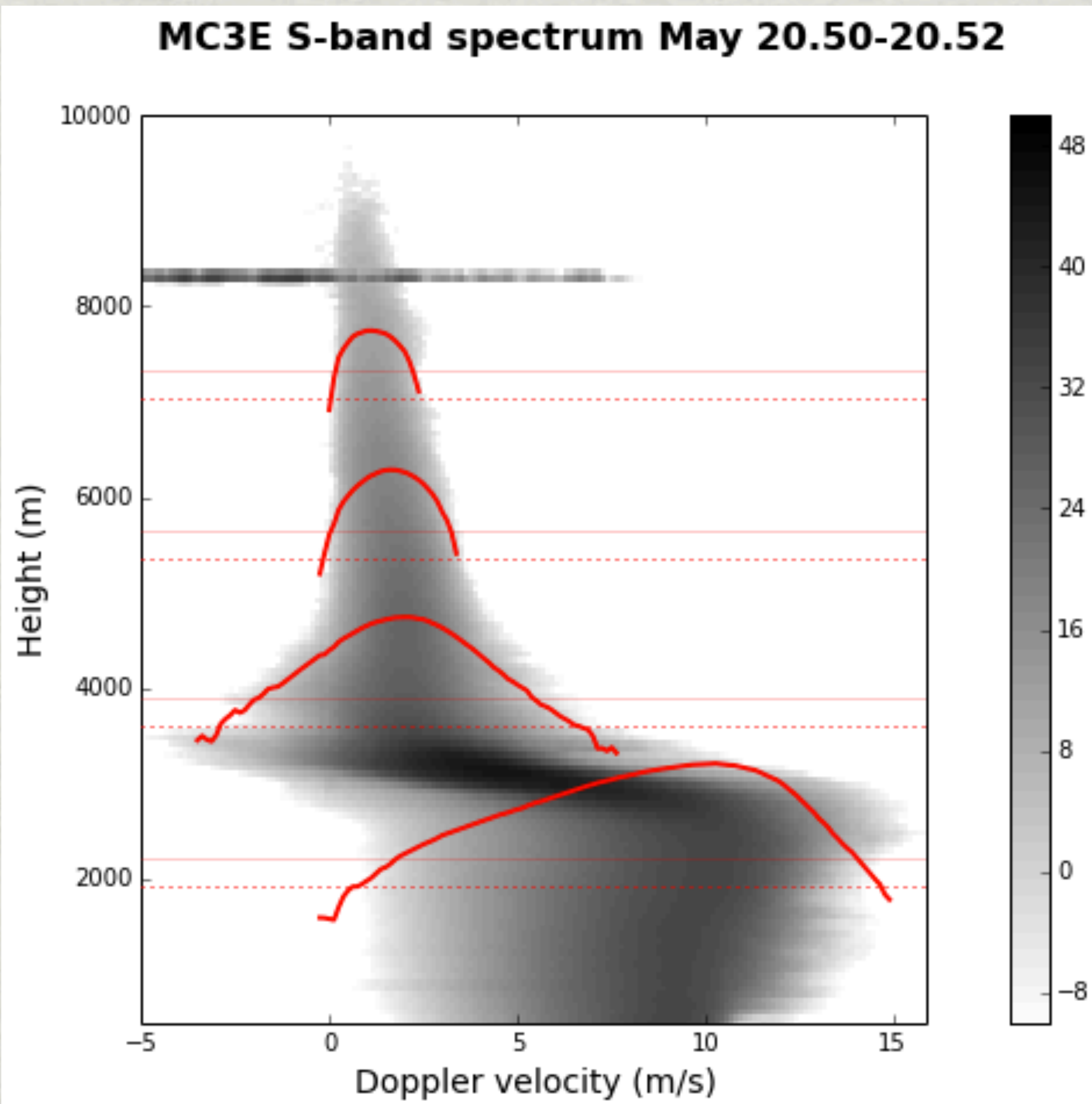
MC3E

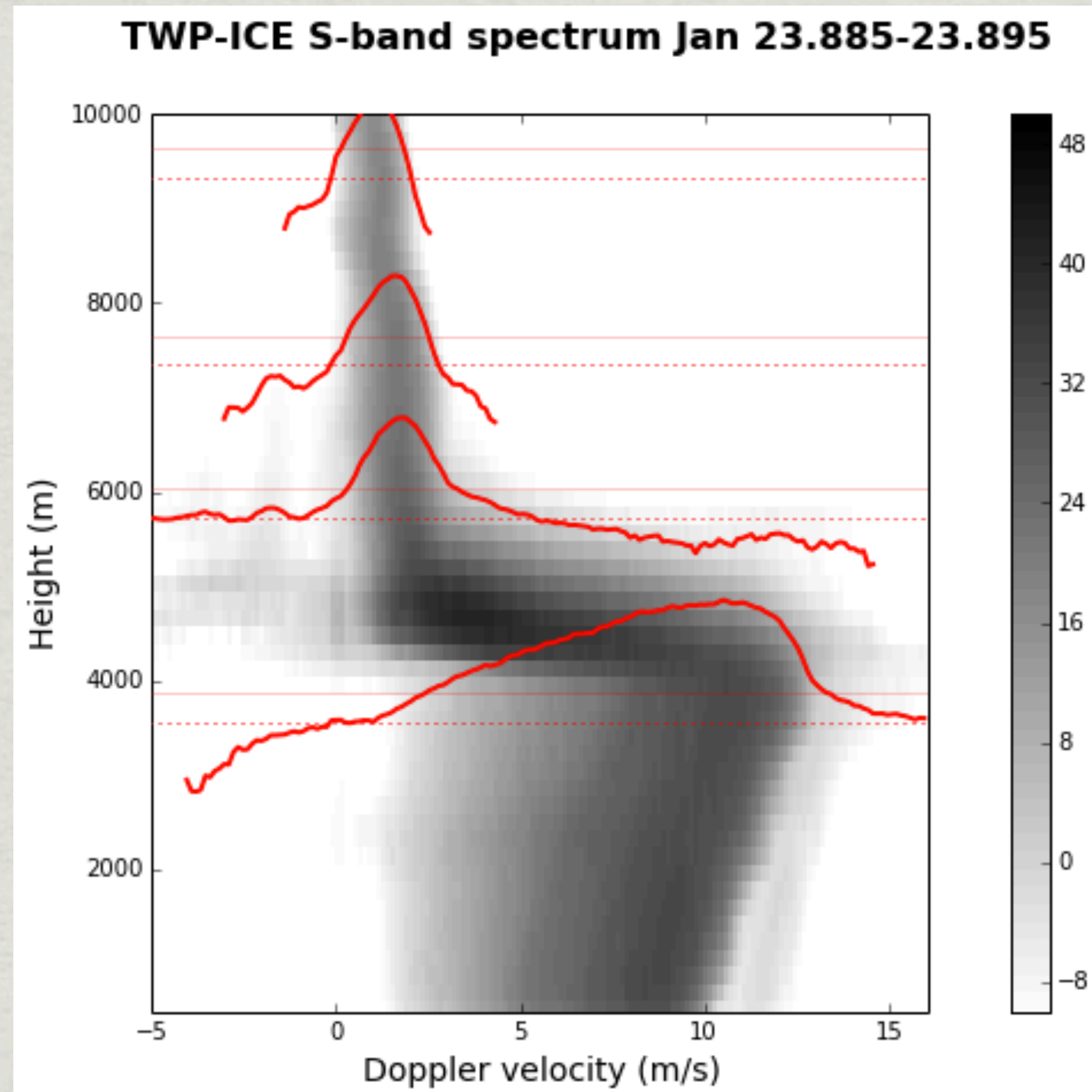


Doppler spectra & the Bayesian aproach

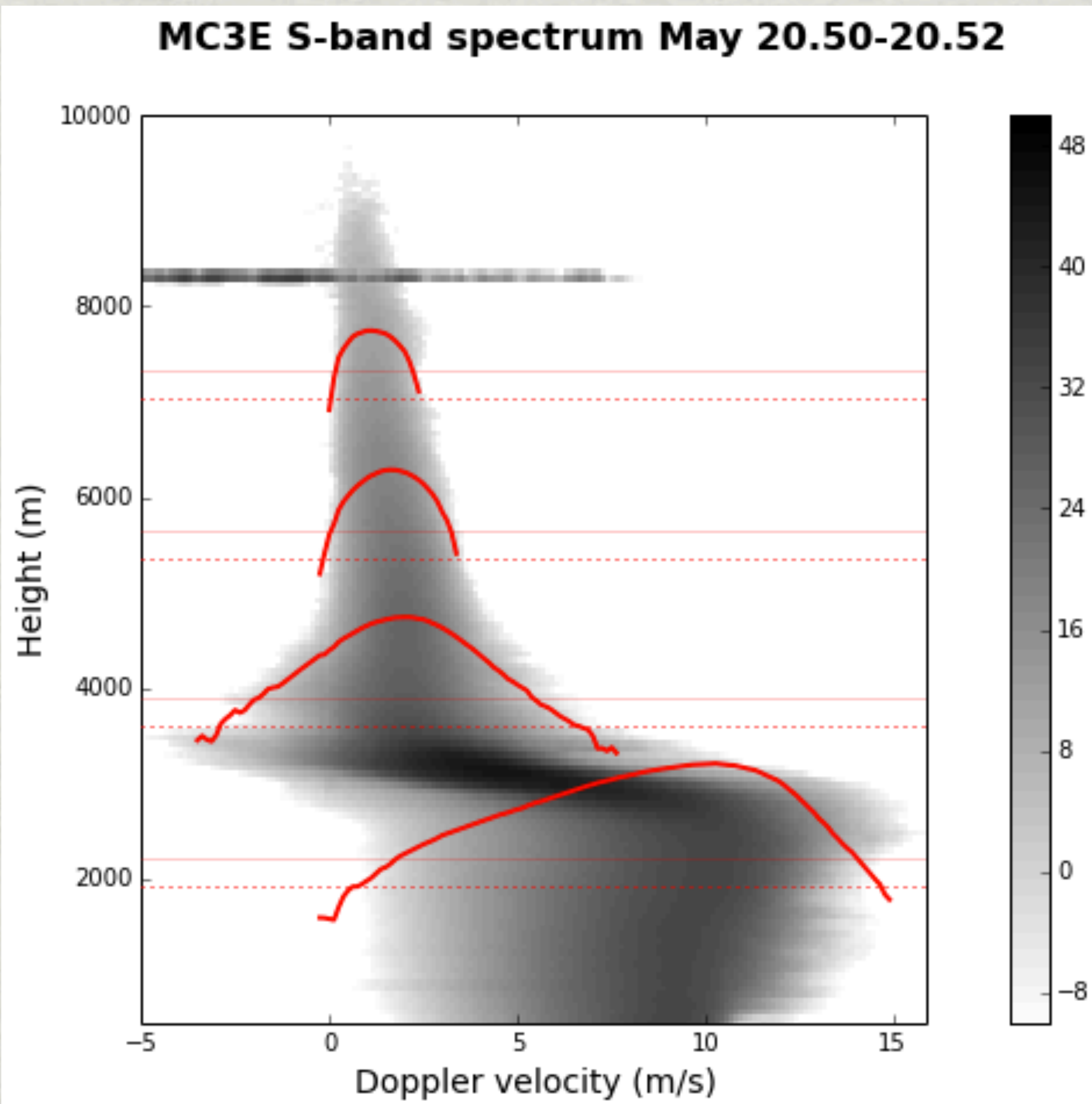
- Doppler spectra from S- and K-band profiling radars provide detailed information on vertical variability of ice (& ice sticking efficiency)
- We can simulate these conditions well -> let the observations directly constrain the microphysics
- We would like to consider all sources of uncertainty & multivariate uncertainty -> Bayes
- Coauthors: Ann Fridlind, Andrew Ackerman, Christopher Williams, Gregory McFarquhar, Wei Wu, Xiquan Dong, Jingyu Wang, Alexei Korolev, Alice Grandin, Walter Strapp

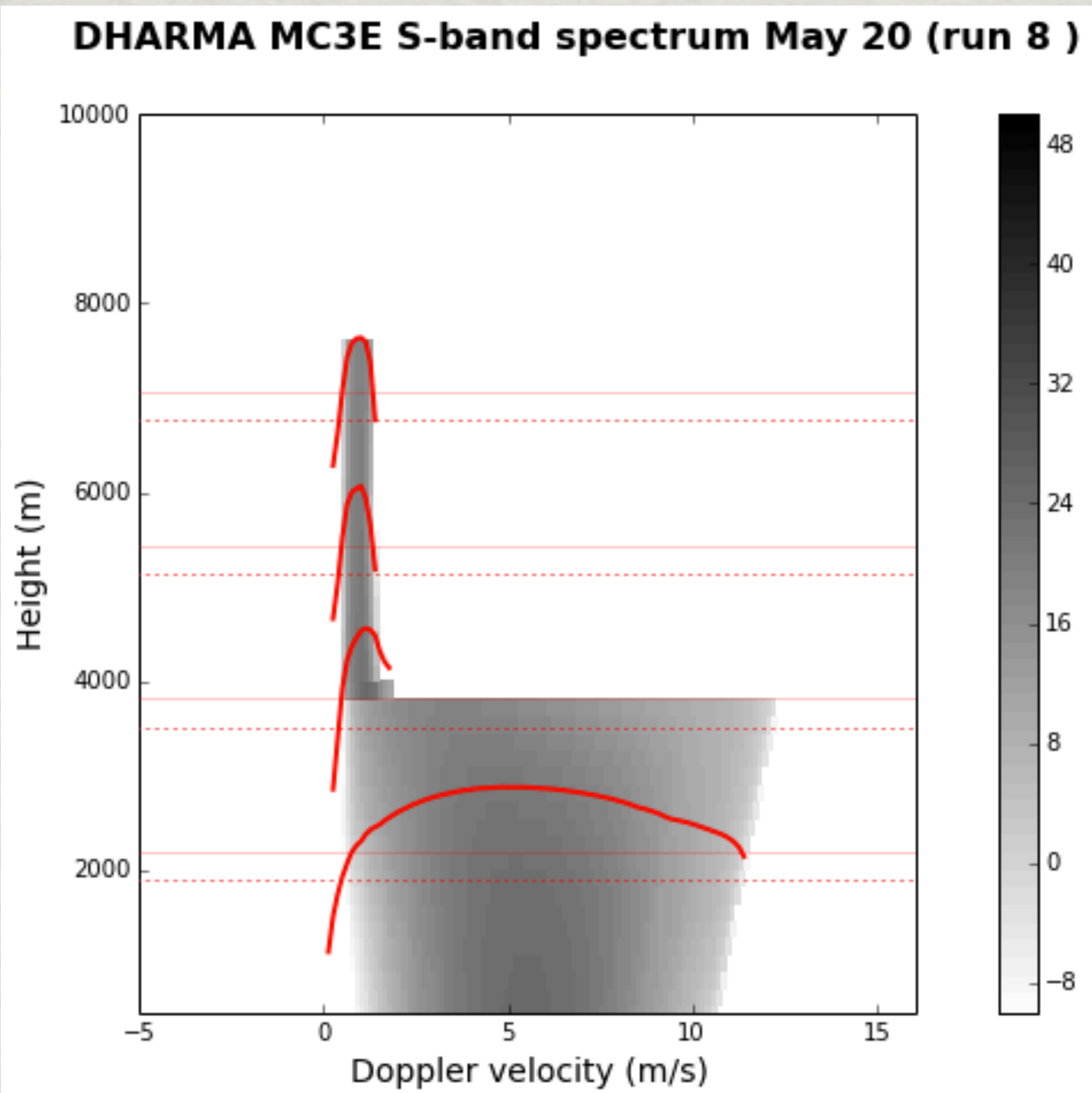
Radar Doppler Spectra



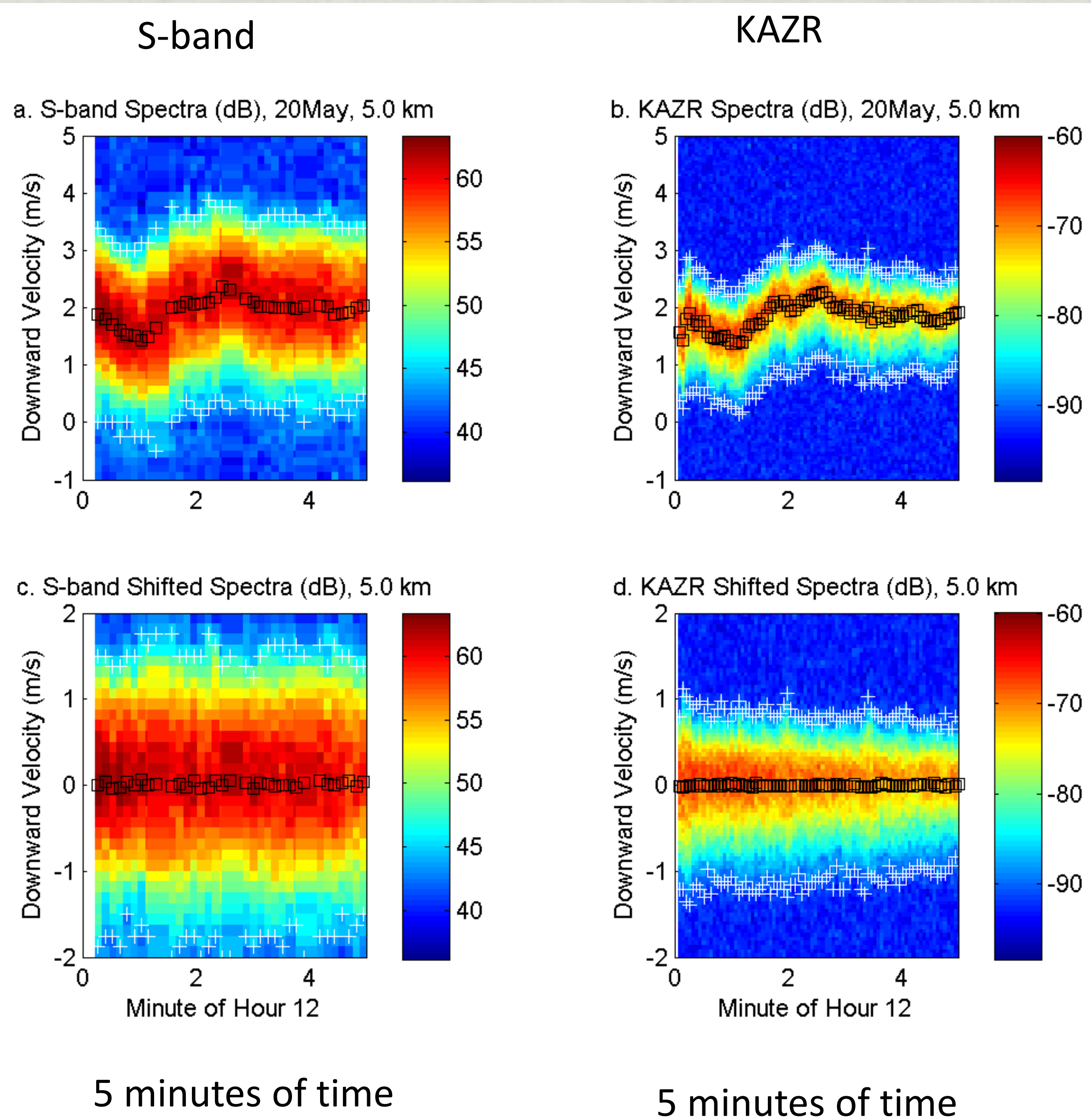


Radar Doppler Spectra





S-band vs. KAZR



Time-Spectra cross-sections

Spectra: 5 km

Time: 12:00 to 12:05 UTC

Observed Spectra

Colors are 10log(S(v))

Vmean shifted Spectra

Colors are 10log(S(v))

ANALYSIS BY C. WILLIAMS

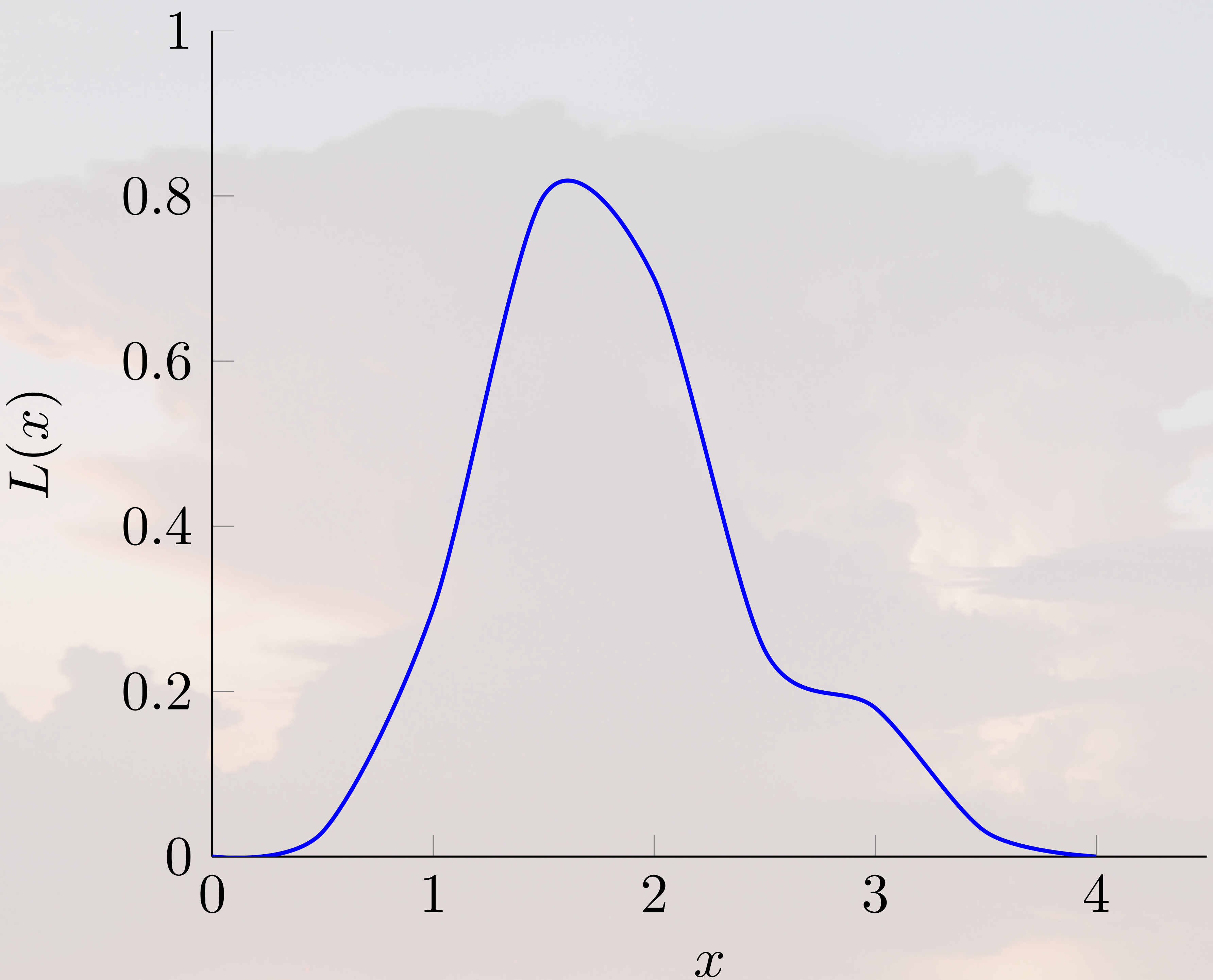
Markov chain Monte-Carlo (MCMC)

General idea:

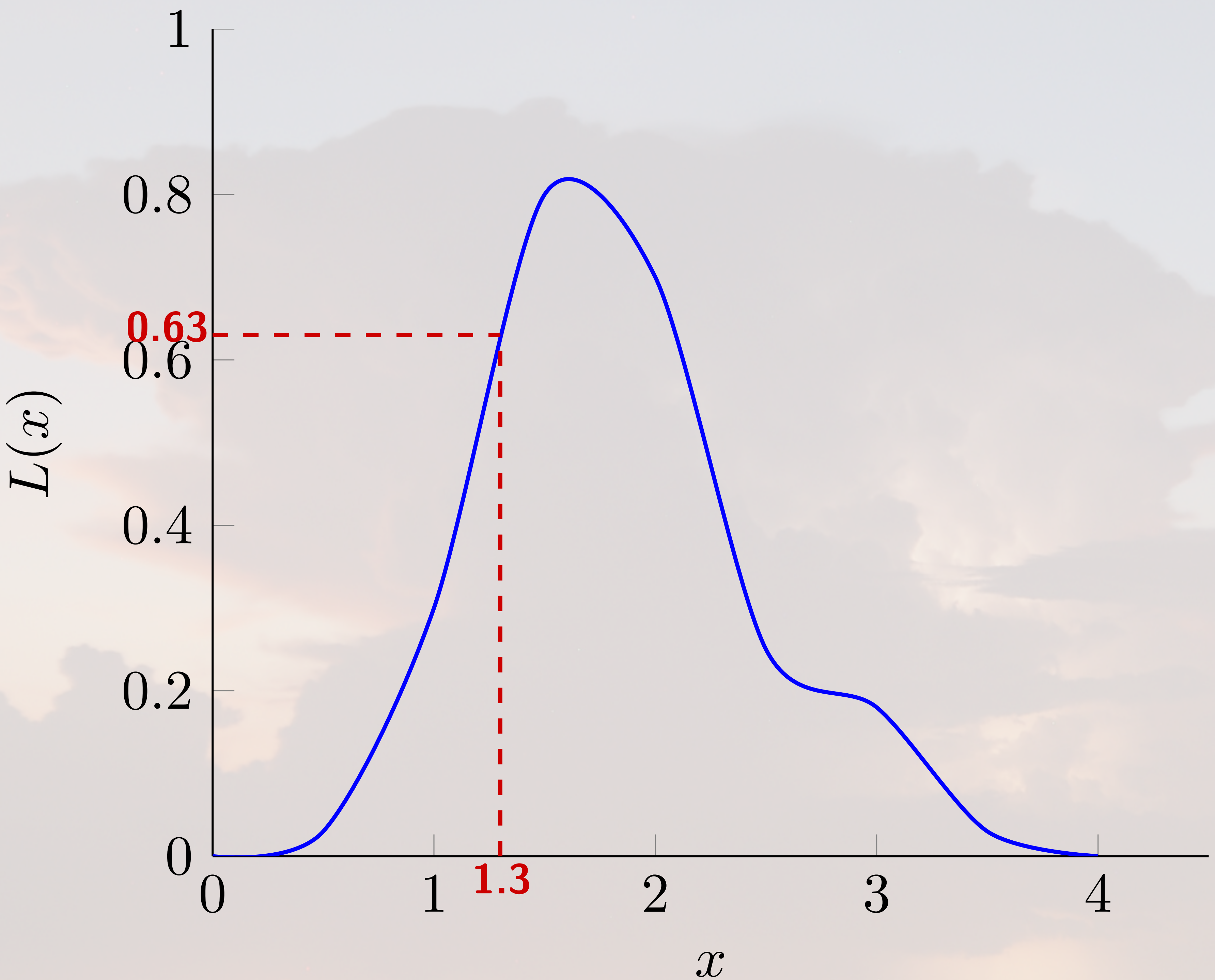
- Use a modified random walk (a Markov chain) to sample the parameter space
- Samples in chain are draws from the target distribution
- Random walk can be Gaussian or uniform (or anything else)
- Each new sample depends *only* on the previous sample (Markovian property).
- Each new sample is accepted or rejected depending on probabilities of the current & proposal samples:

$$P(\mathbf{x}_{prop}|\mathbf{x}_{curr}) = min[1, P(\mathbf{x}_{prop})/P(\mathbf{x}_{curr})] \tag{1}$$

MCMC (Metropolis) example



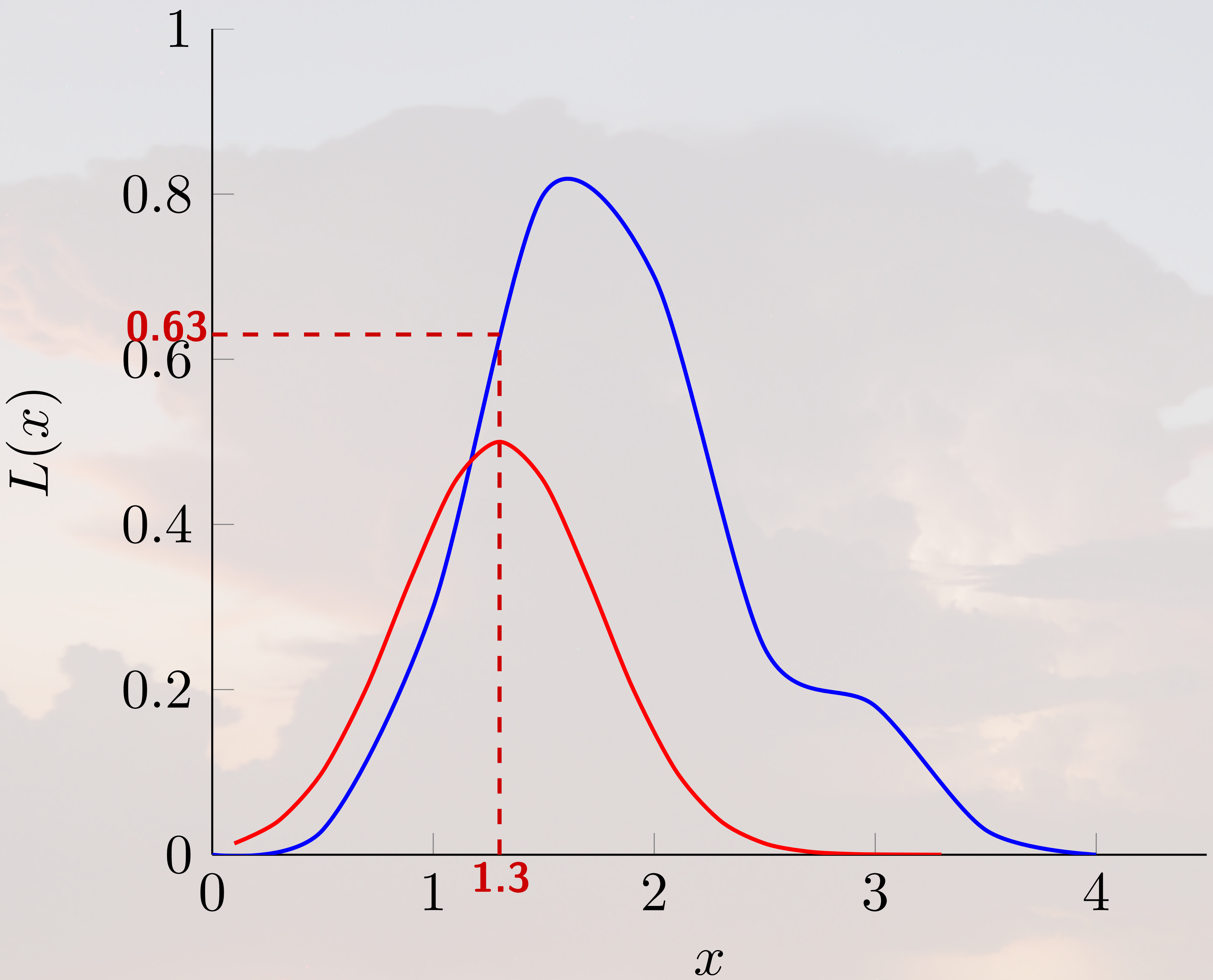
MCMC (Metropolis) example



Markov Chain

i	x(i)
1	1.3

MCMC (Metropolis) example



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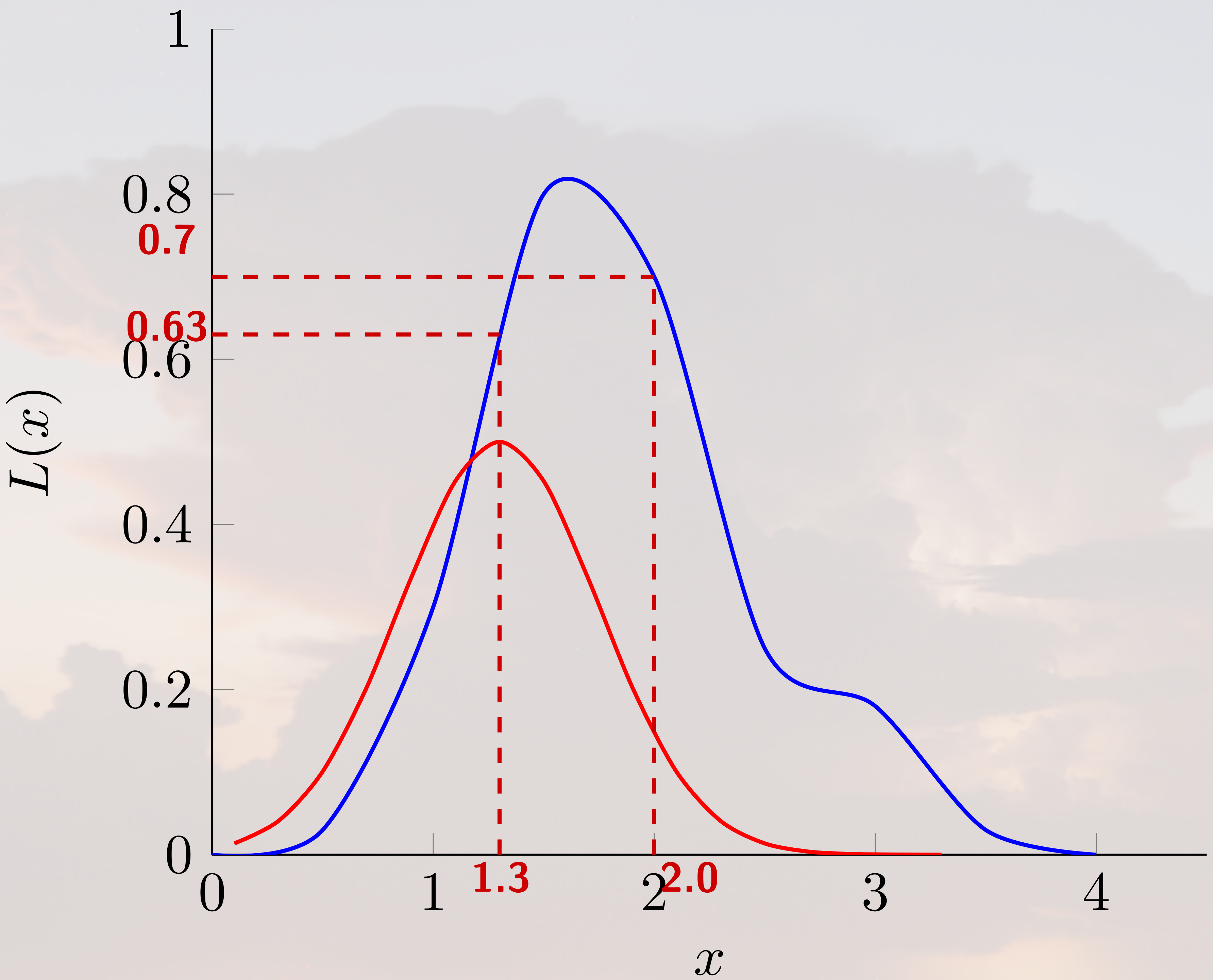
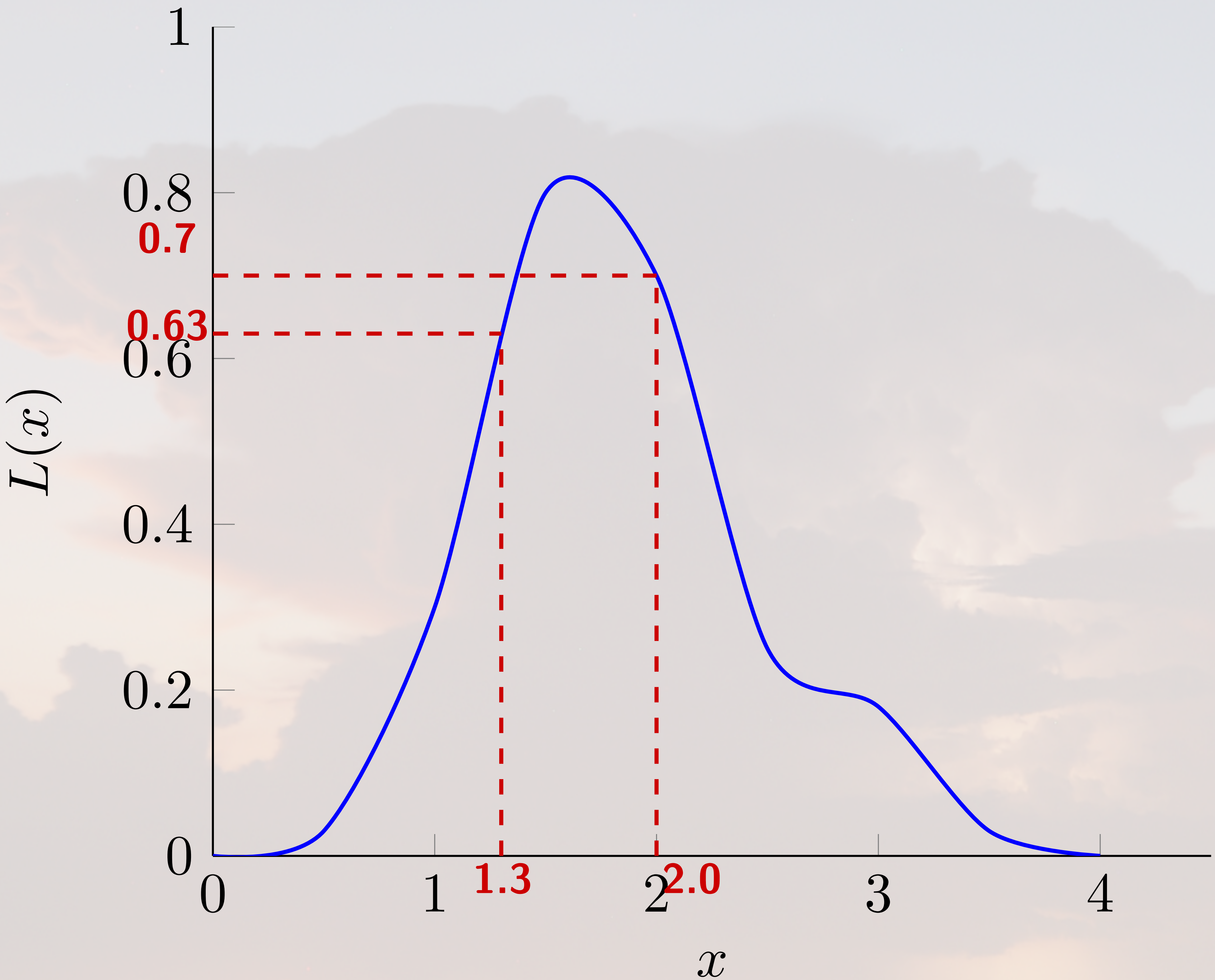


Markov Chain

i	x(i)
1	1.3

MCMC (Metropolis) example

Acceptance probability $= 0.70/0.63$



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1	1.3

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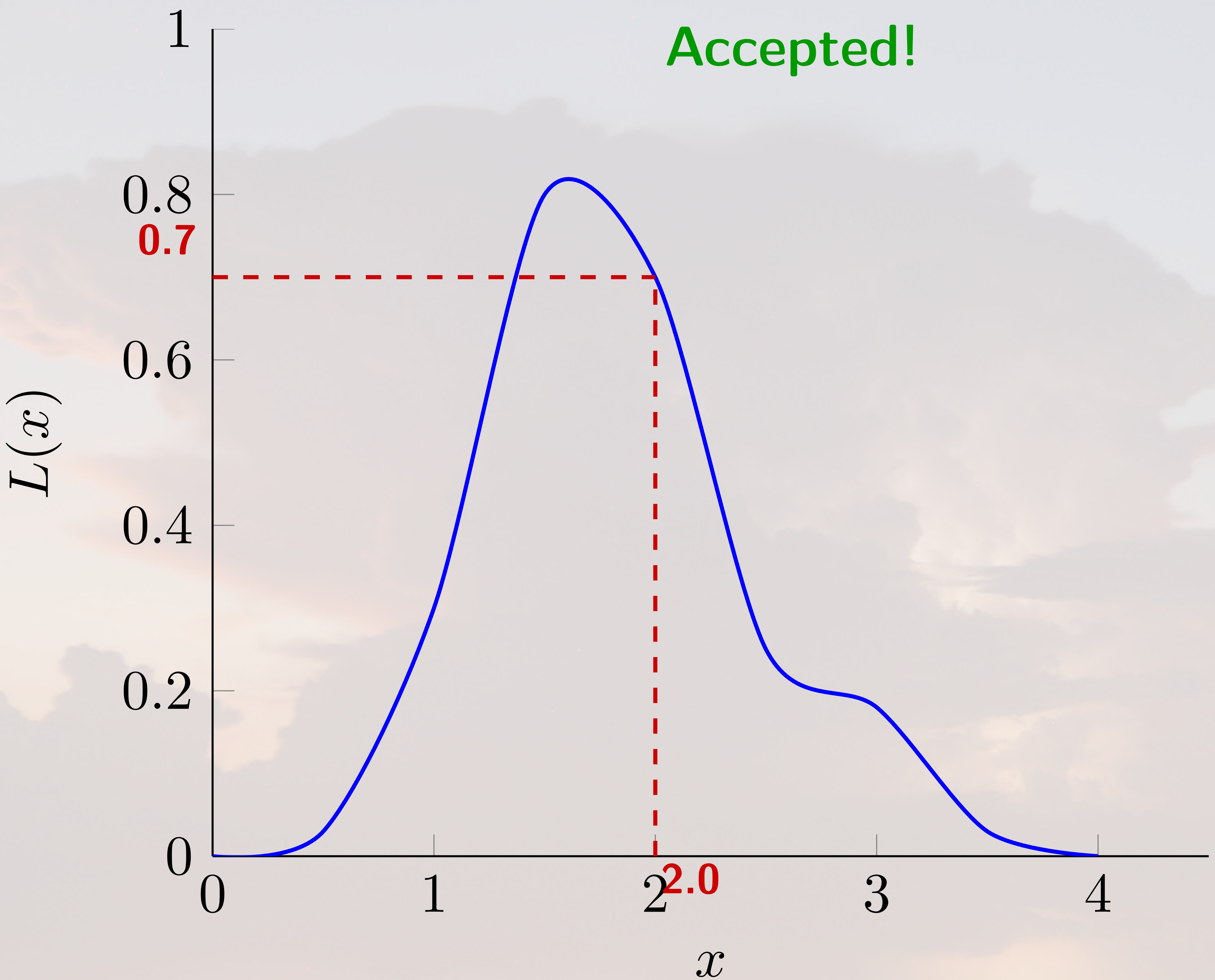
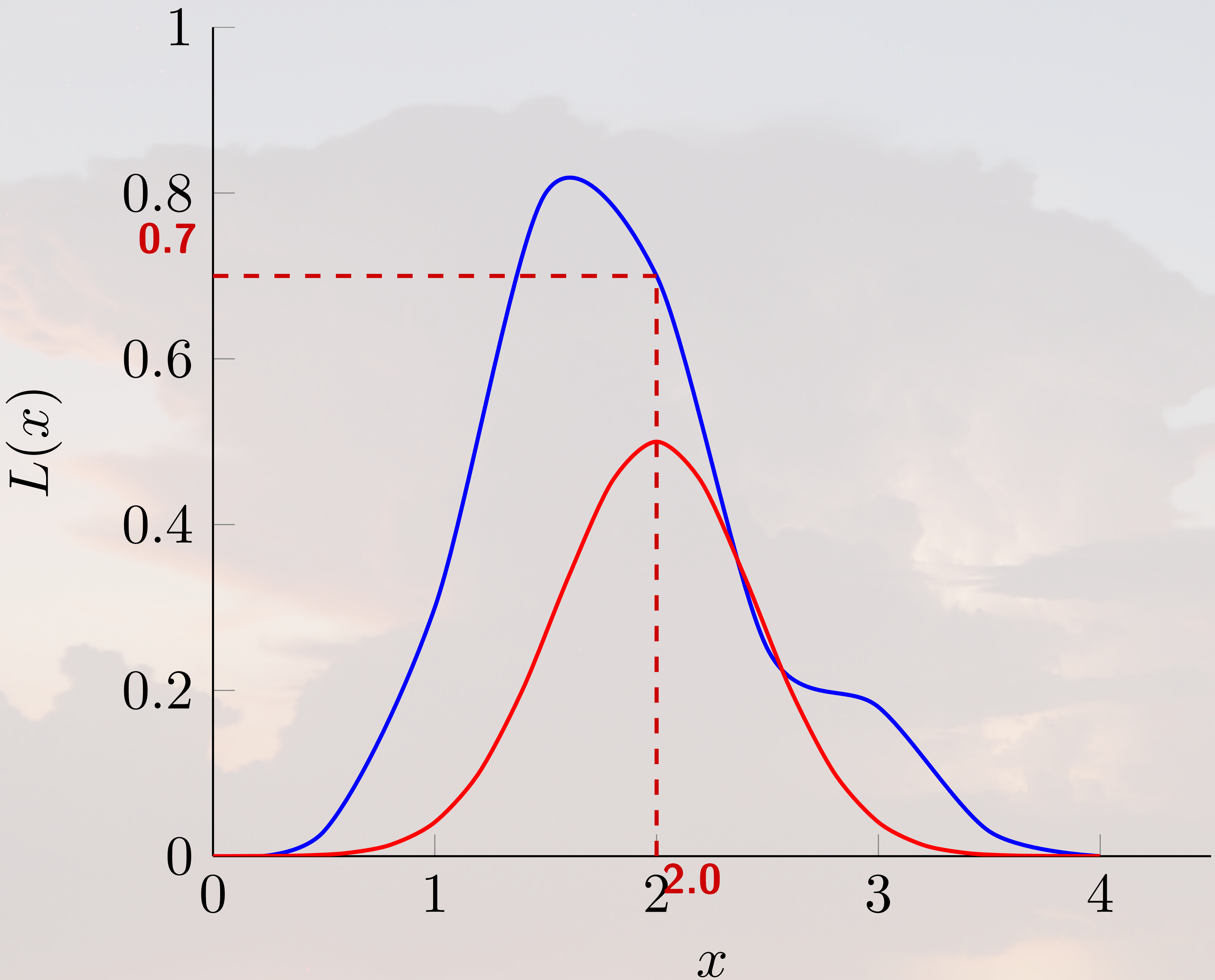


Markov Chain

i	x(i)
1	1.3
2	2.0

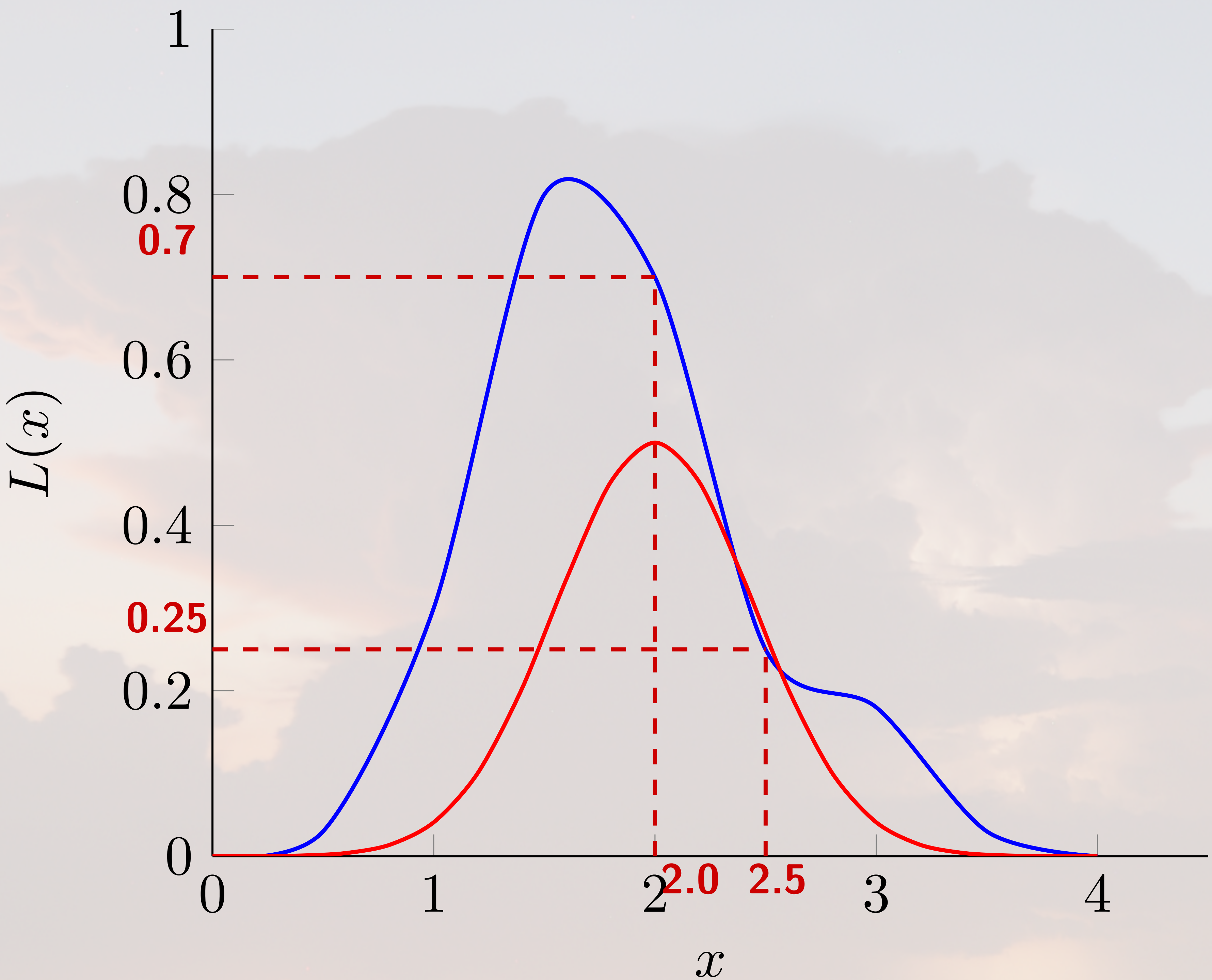
MCMC (Metropolis) example



Markov Chain

i	x(i)
1	1.3
2	2.0

MCMC (Metropolis) example



Markov Chain

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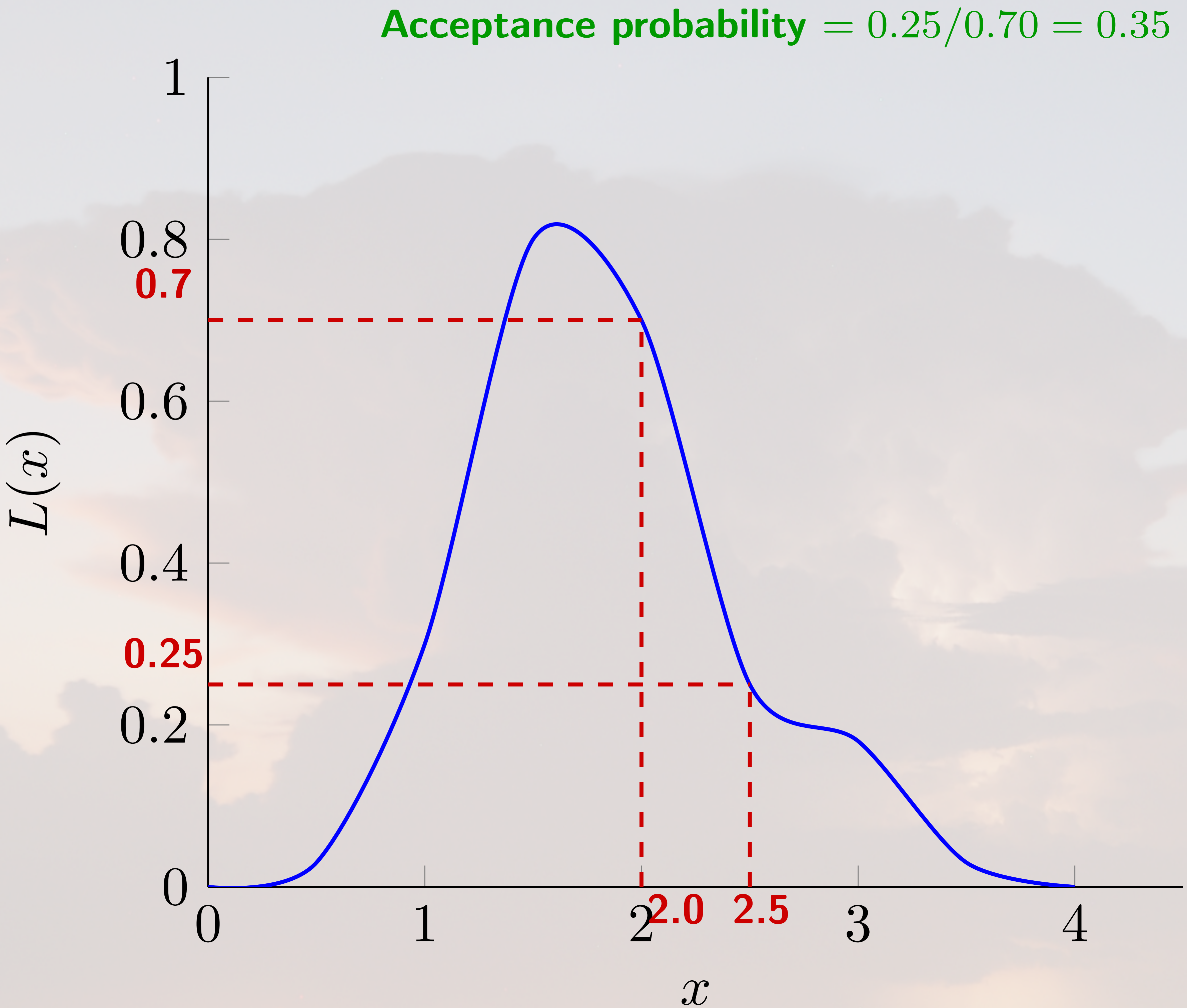
1	1.3
2	2.0

MCMC (Metropolis) example

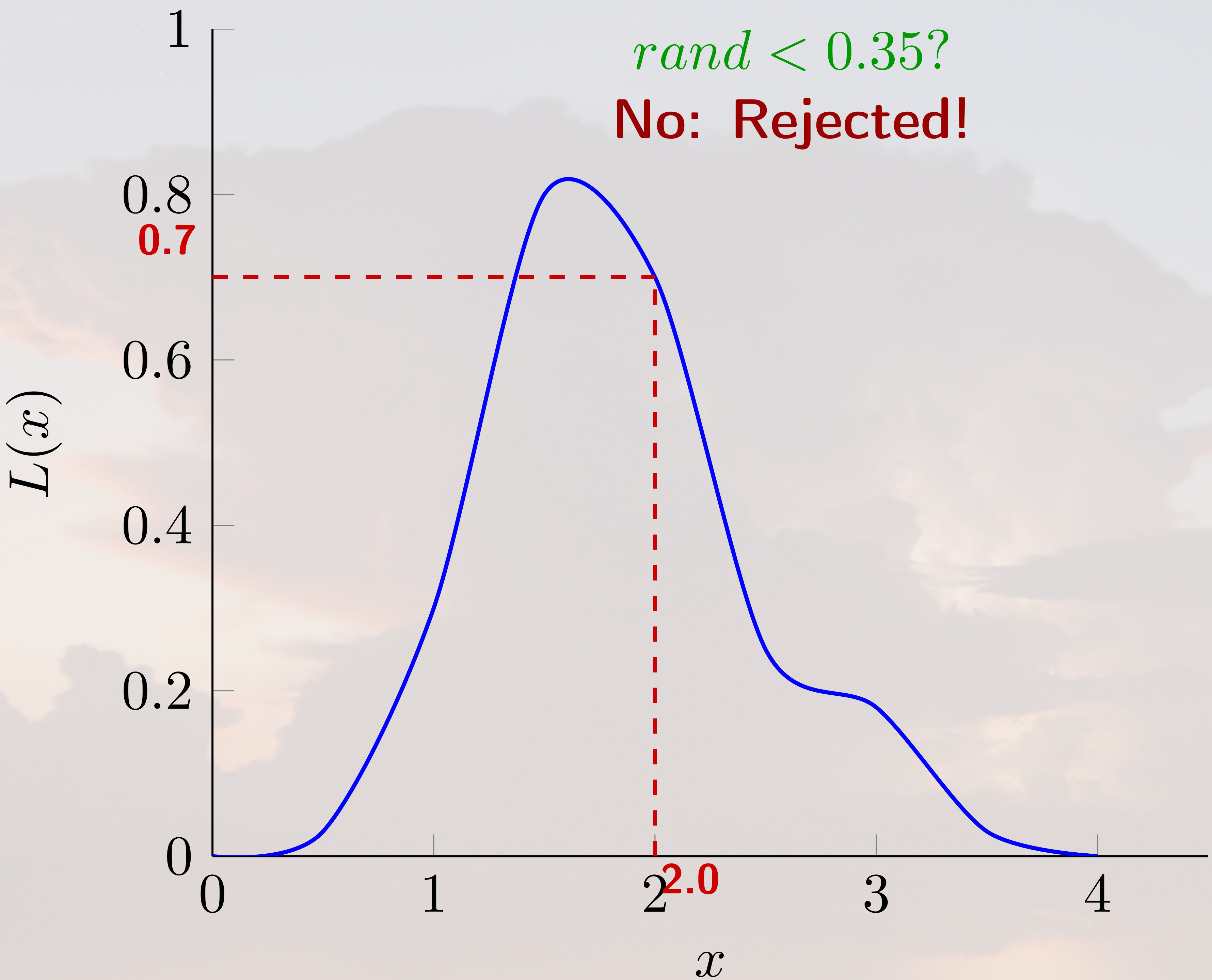


Markov Chain

i	x(i)
1	1.3
2	2.0

MCMC (Metropolis) example

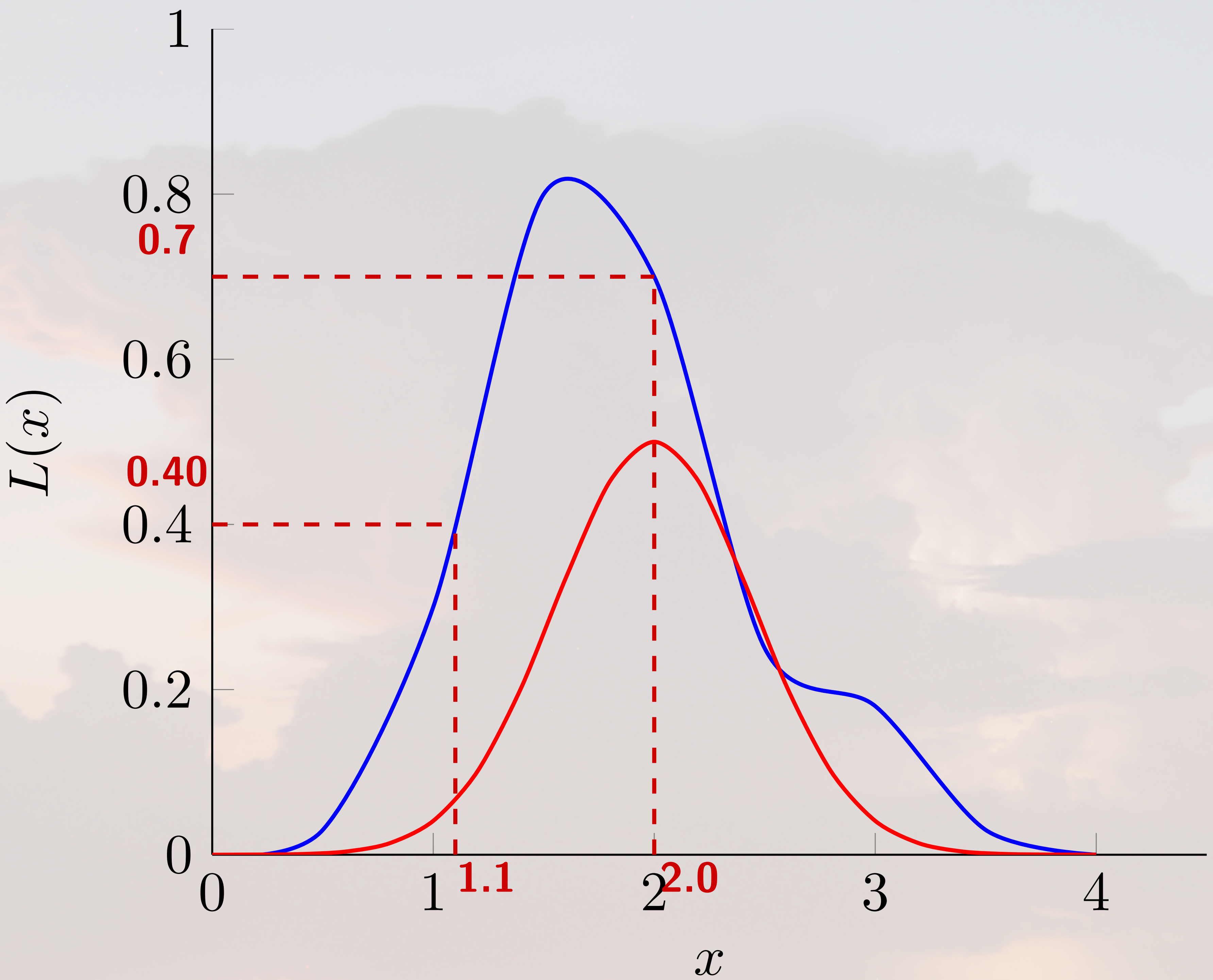
Acceptance probability $= 0.25/0.70 = 0.35$



Markov Chain

i	x(i)
1	1.3
2	2.0
3	2.0

MCMC (Metropolis) example

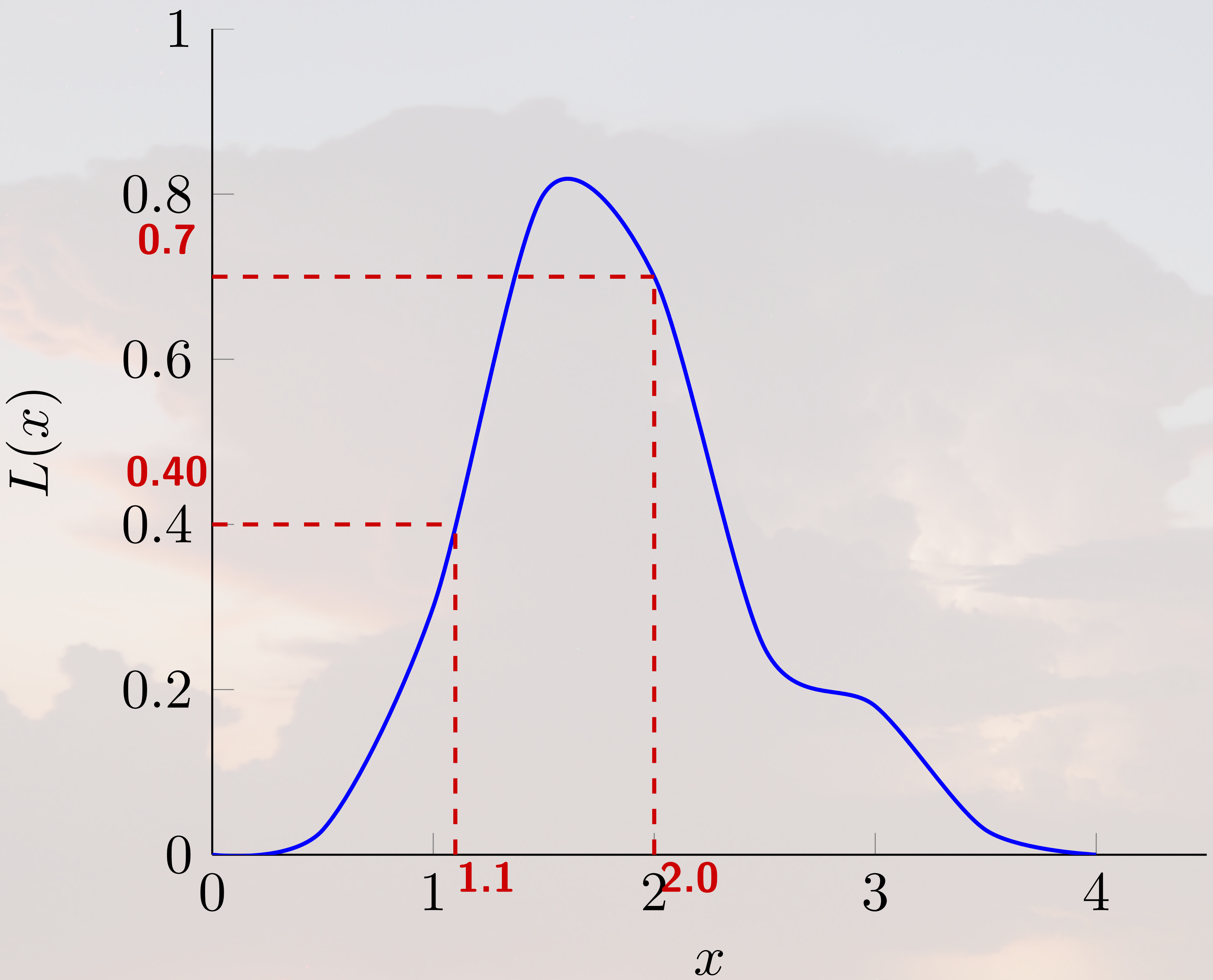


Markov Chain

i	x(i)
1	1.3
2	2.0
3	2.0

MCMC (Metropolis) example

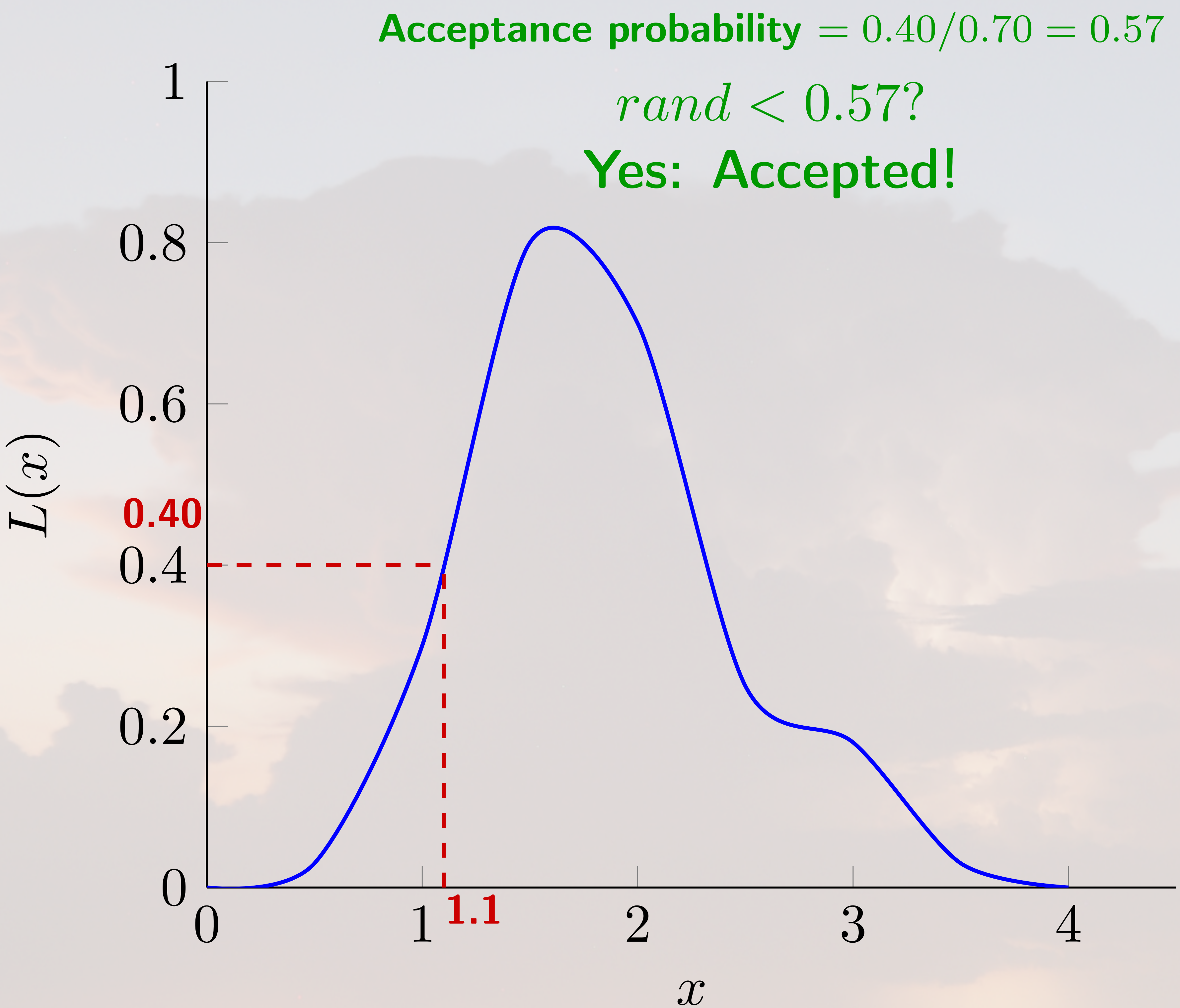
Acceptance probability $= 0.40/0.70 = 0.57$



Markov Chain

i	x(i)
1	1.3
2	2.0
3	2.0

MCMC (Metropolis) example

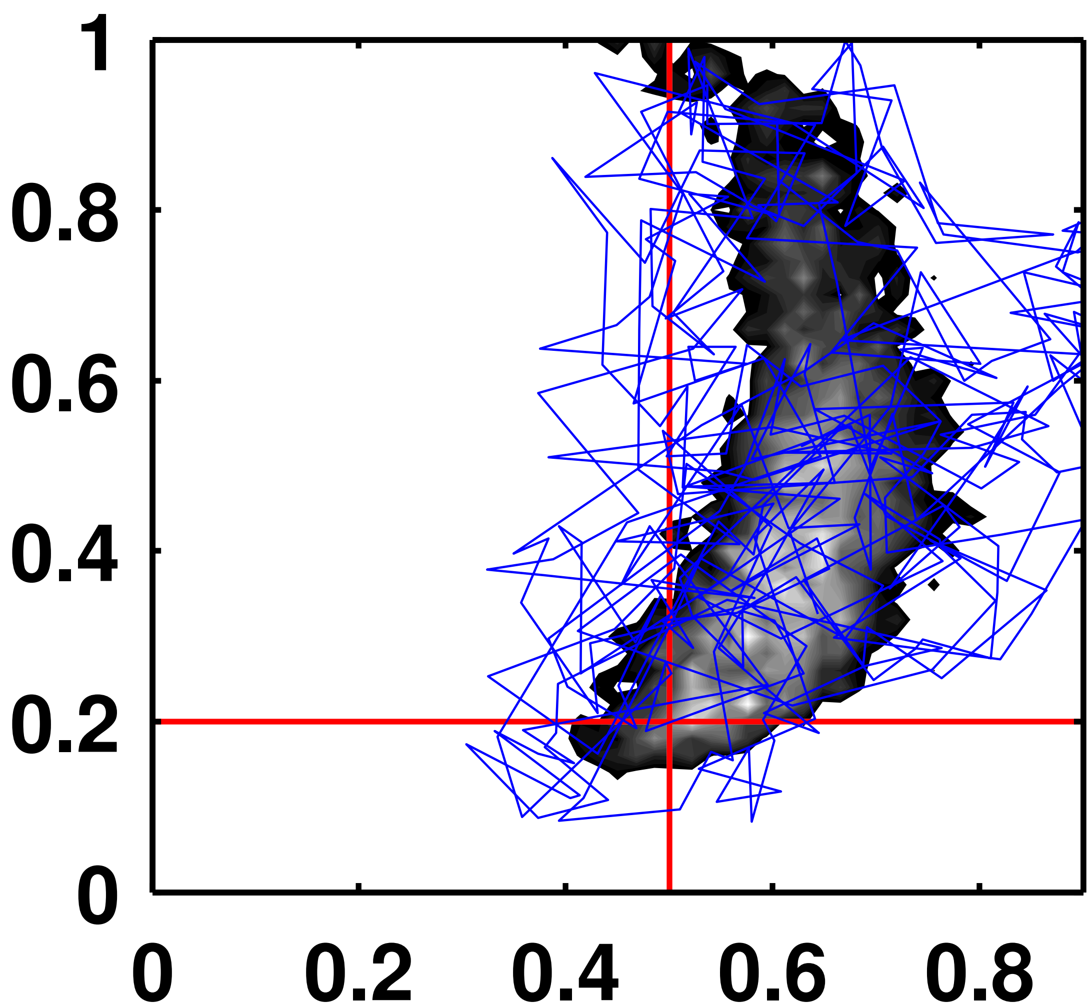


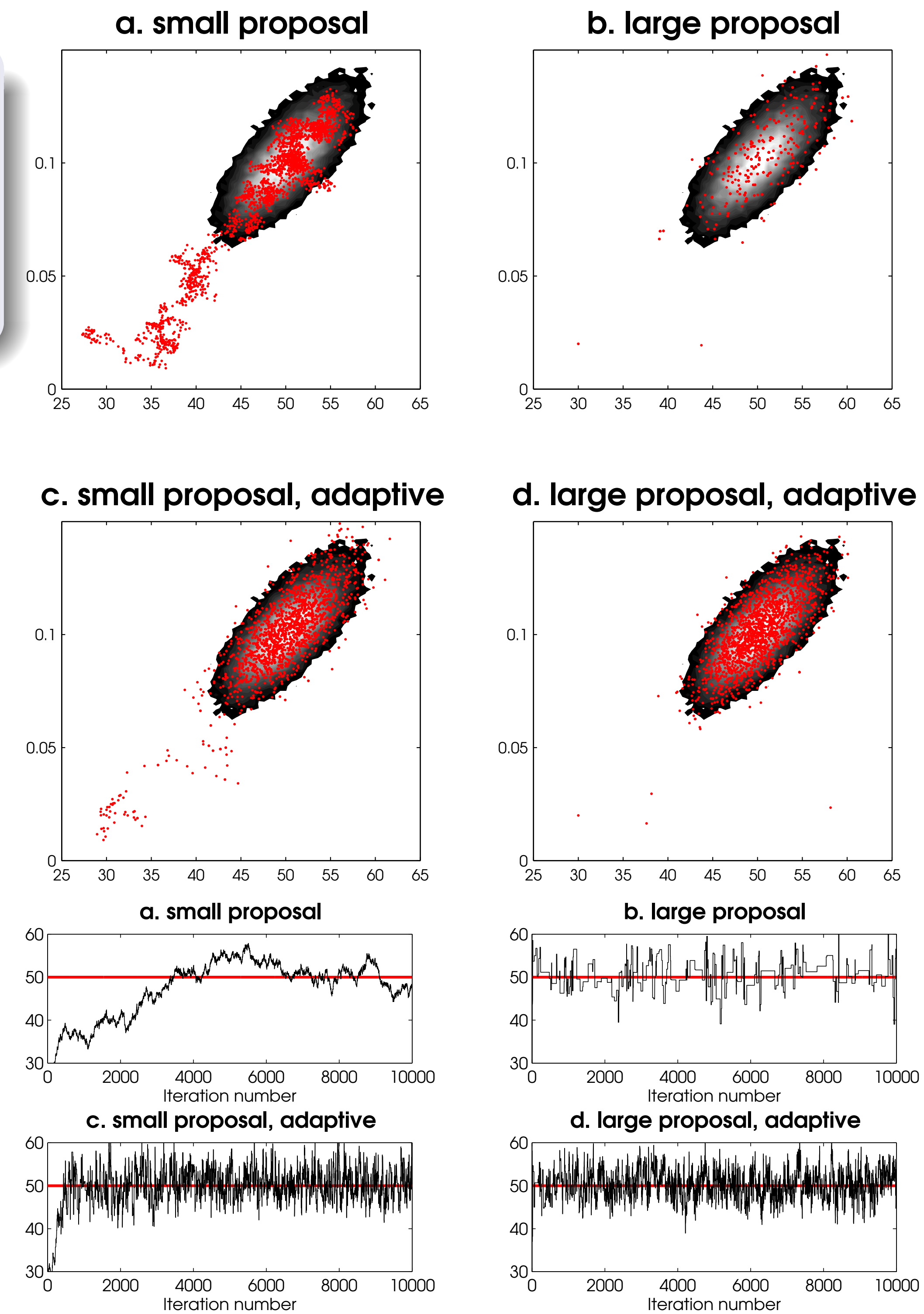
Markov Chain

i	x(i)
1	1.3
2	2.0
3	2.0
4	1.1

Markov Chain Monte Carlo probabilistic sampling

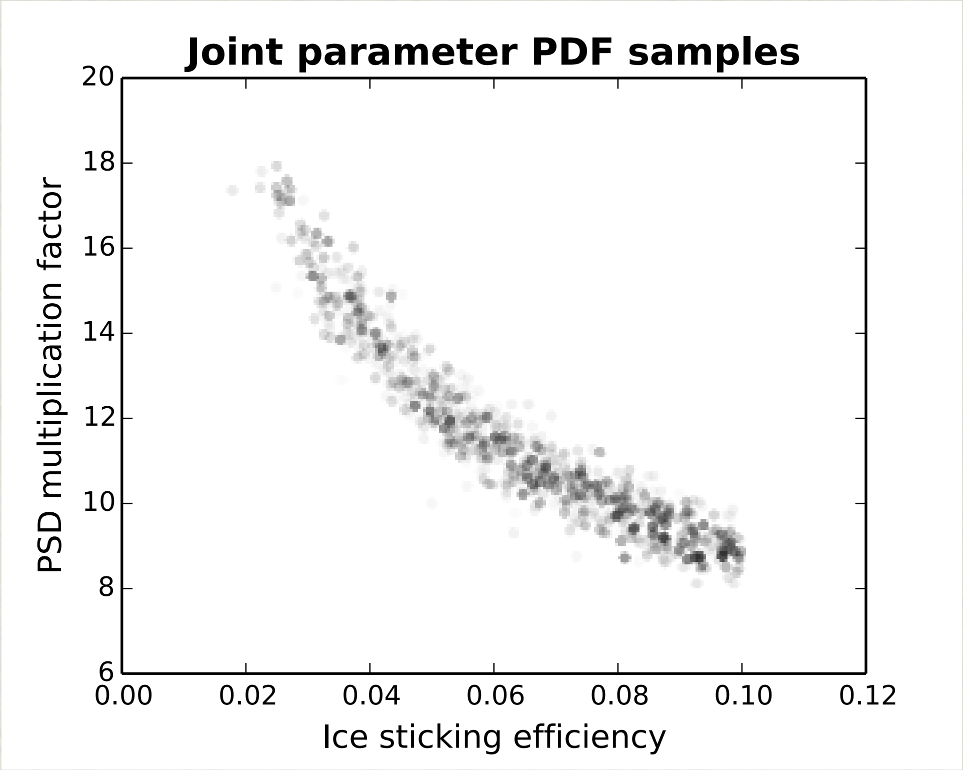
MCMC sampler proposes steps in parameter space, accepting/rejecting according to comparison of model to obs

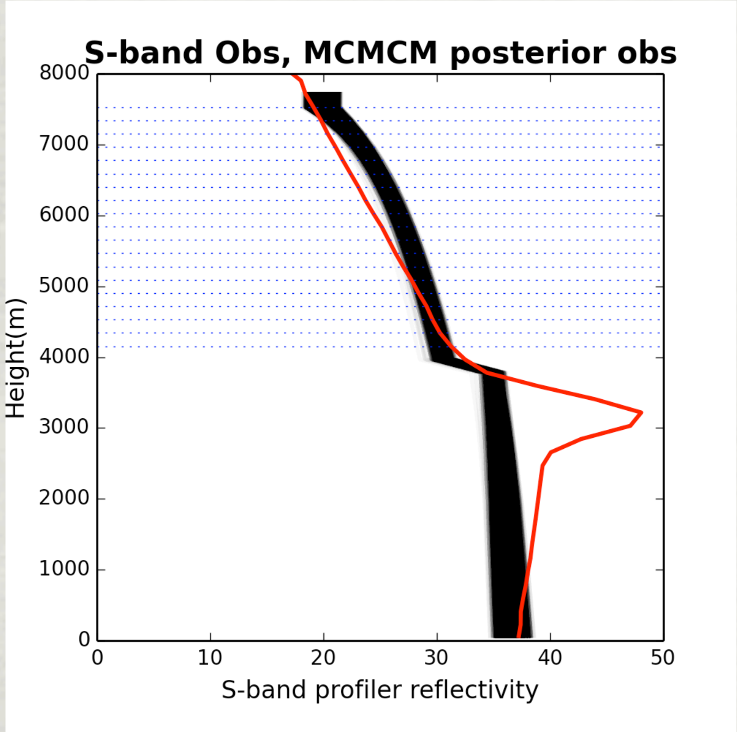




MCMC results

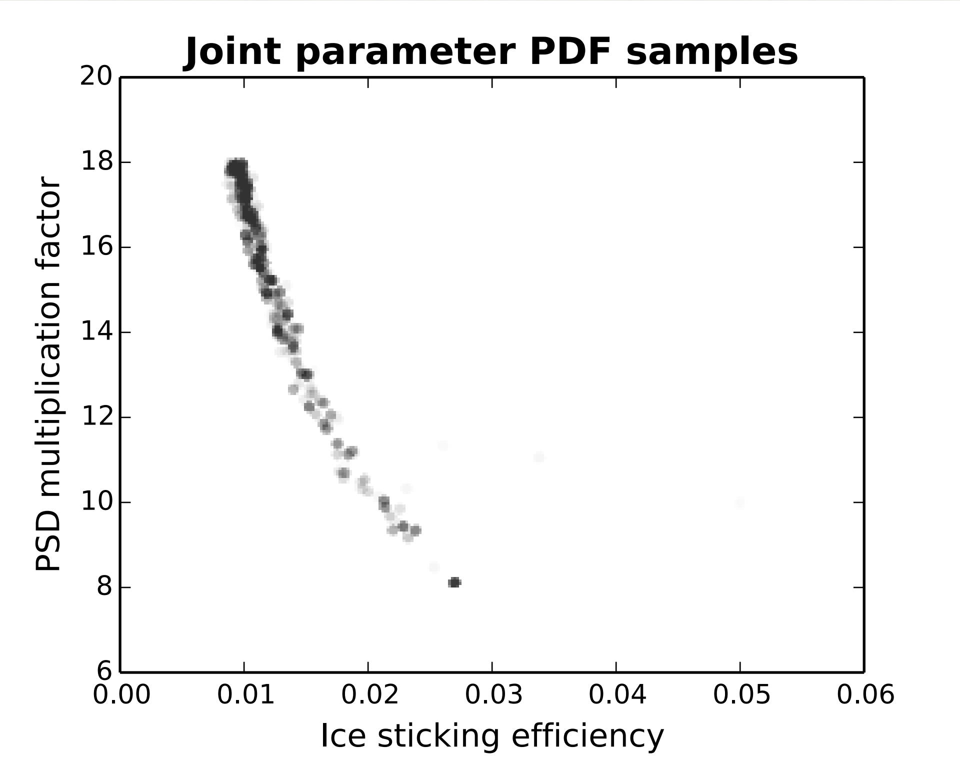
- Preliminary results:
  - constraint only by 0th moment of Doppler spectrum (reflectivity
  - Perturbed parameters: Ice sticking efficiency (global), Total ice mass multiplier (uncertainty in initial ice mass
  - van Diedenhoven et al 2012 ice treatment

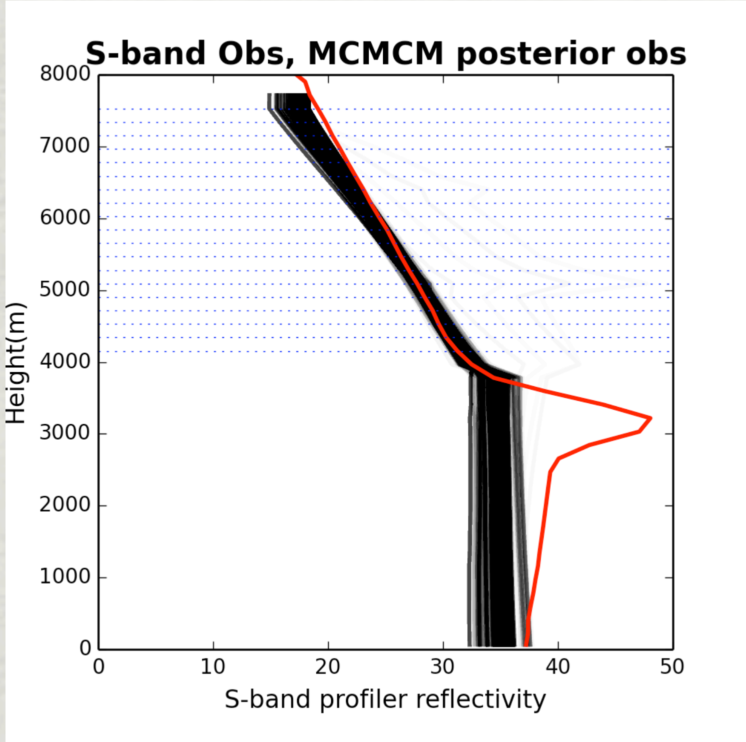




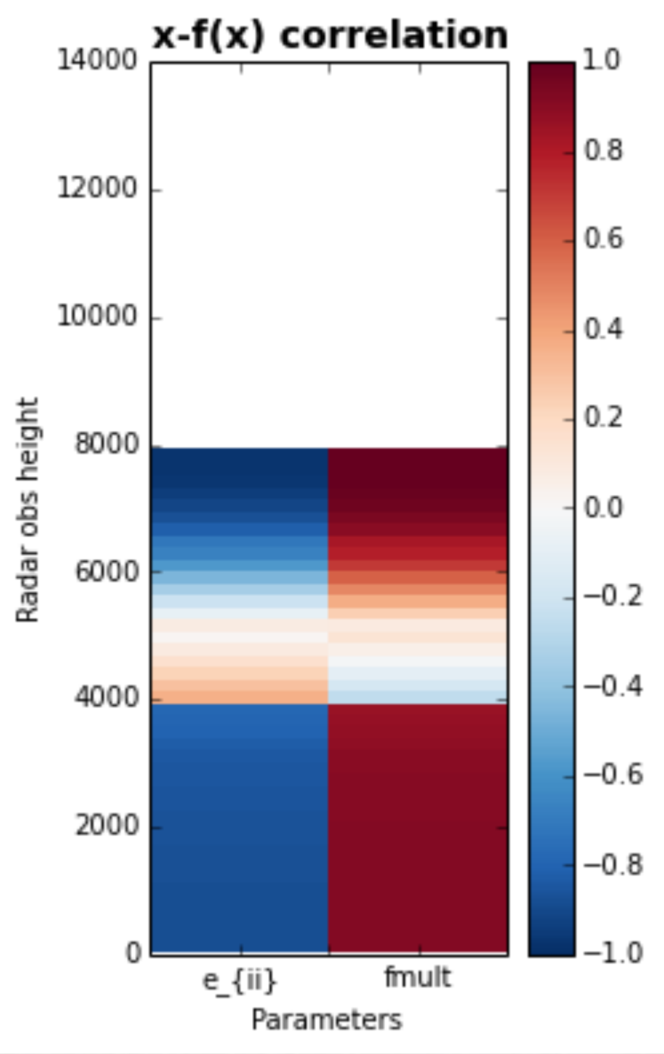
MCMC results

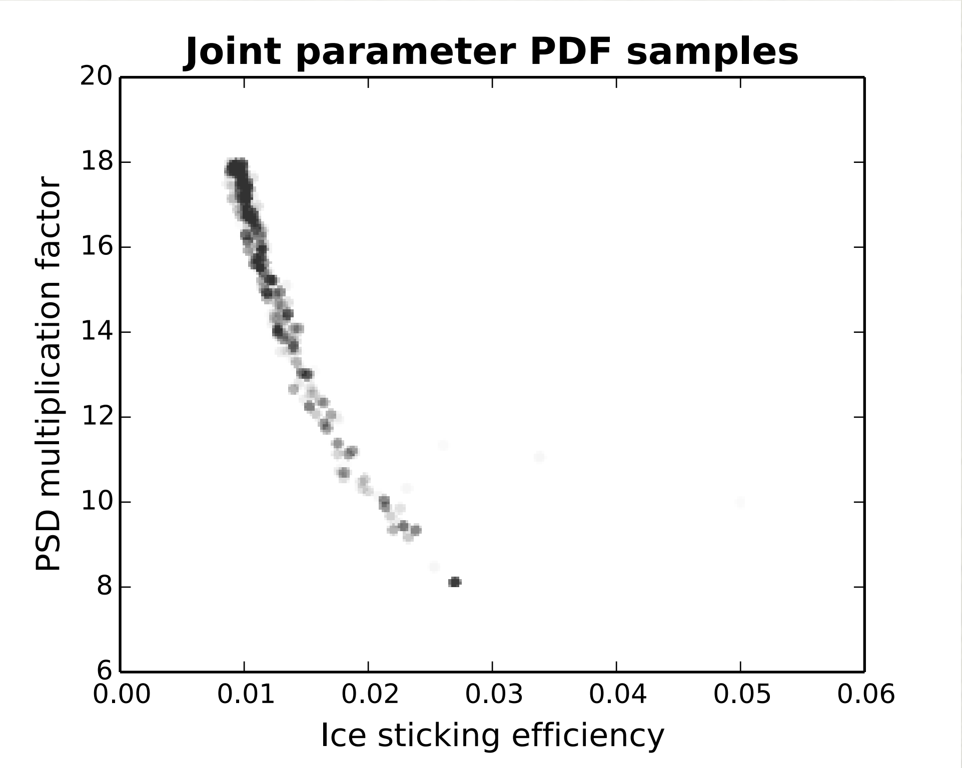
- Preliminary results:
  - constraint only by 0th moment of Doppler spectrum (reflectivity
  - Perturbed parameters: Ice sticking efficiency (global), Total ice mass multiplier (uncertainty in initial ice mass
  - Brown & Francis 1995 ice treatment

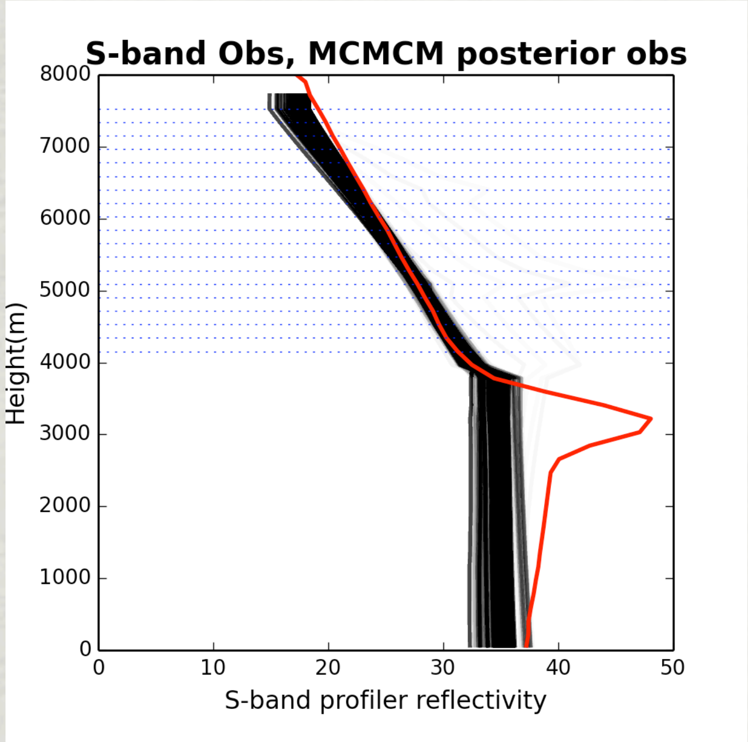




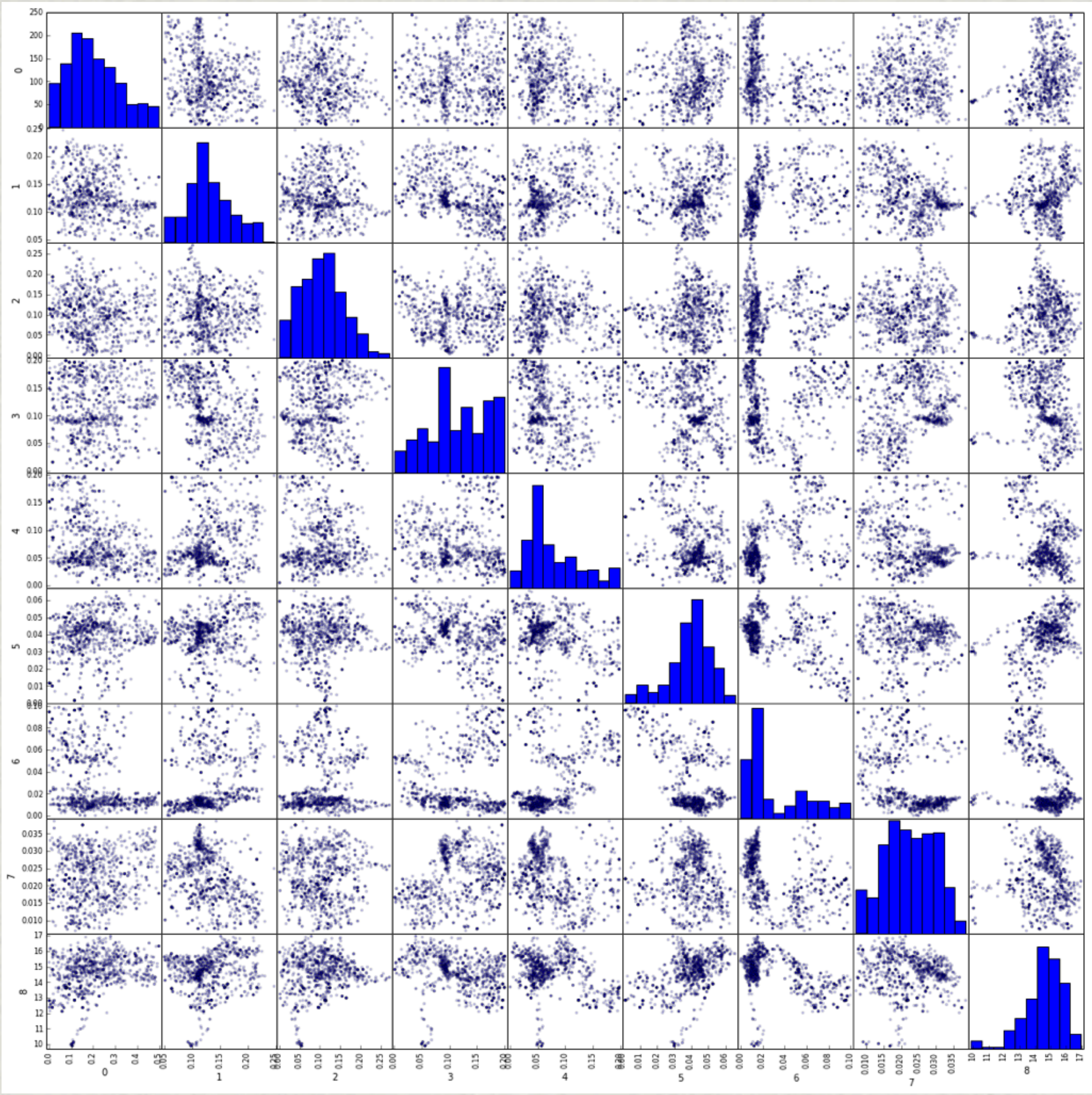
MCMC results

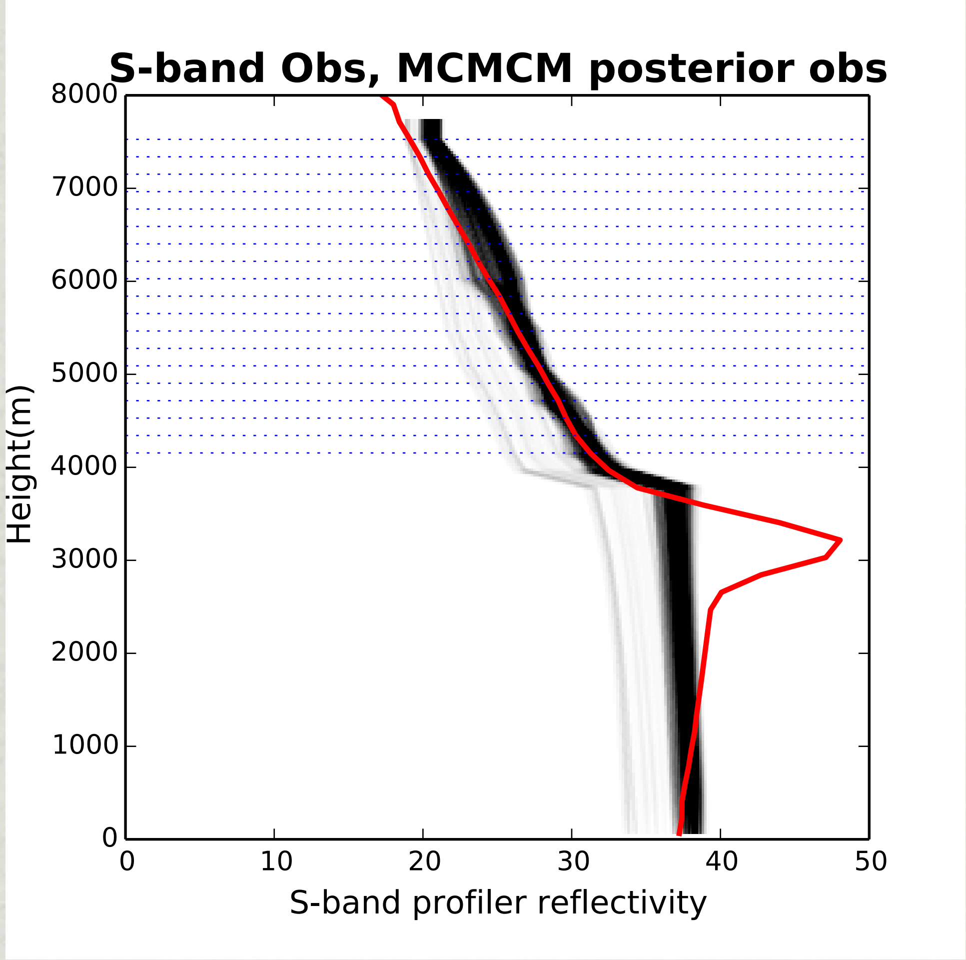






Temperature-dependent Ice sticking efficiency





Summary

- Radar Doppler spectrum being used in probabilistic (Bayesian) framework to estimate microphysical parameters in the presence of model uncertainty and observational error
- Ongoing work:
  - Utilize full Doppler spectrum from KAZR
  - Robustly estimate temperature-dependence (and other dependence) of ice sticking
  - Investigate relevance of uncertainty to CRMs and GCMs

KAZR AIR VELOCITY ESTIMATE (DOWNWARD BIASED)